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Operation Heli-STAR - Atlanta Communications Experiment (ACE)

December 1996

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Atlanta Short-haul Transportation System (ASTS)
Communication/Navigation/Surveillance
Atlanta Communications Experiment (ACE)
Operation Heli-STAR (HELicopter - Short-haul
Transport and Aviation Research)

AGATE Flight Systems Communication Work
Package 1.4

Final Report



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16. Abstract <p>Operation Heli-STAR (Helicopter Short-Haul Transportation and Aviation Research) was established and operated in Atlanta, Georgia, during the period of the 1996 Centennial Olympic Games. Heli-STAR had three major thrusts: 1) the establishment and operation of a helicopter-based cargo transportation system, 2) the management of low-altitude air traffic in the airspace of an urban area, and 3) the collection and analysis of research and development data associated with items 1 and 2. Heli-STAR was a cooperative industry/government program that included parcel package shippers and couriers in the Atlanta area, the helicopter industry, aviation electronics manufacturers, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and support contractors.</p> <p>Several detailed reports have been produced as a result of Operation Heli-STAR. These include 4 reports on acoustic measurements and associated analyses, and reports on the Heli-STAR tracking data including the data processing and retrieval system, the Heli-STAR cargo simulation, and the community response system. In addition, NASA's Advanced General Aviation Transport Experiments (AGATE) program has produced a report describing the Atlanta Communications Experiment (ACE) which produced the avionics and ground equipment using automatic dependent surveillance-broadcast (ADS-B) technology. This latter report is restricted to organizations belonging to NASA's AGATE industry consortium. A complete list of these reports is shown on the following page.</p>					
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Volume 2 DOT/FAA/ND-97/10	Operation Heli-STAR - Helicopter Noise Levels Near Dekalb Peachtree Airport; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Marcie Benne, Mary L. Rivamonte, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 3 DOT/FAA/ND-97/11	Operation Heli-STAR - Helicopter Noise Annoyance Near Dekalb Peachtree Airport; Krishan Ahuja, Marcie Benne, Mary L. Rivamonte, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 4 DOT/FAA/ND-97/12	Operation Heli-STAR - Helicopter Noise at Heliports; Krishan Ahuja, Robert Funk, Jeffrey Hsu, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
Volume 5 DOT/FAA/ND-97/13	Operation Heli-STAR - Effects of Buildings on Helicopter Noise; Krishan Ahuja, Robert Funk, Jeffrey Hsu, Michael Heiges, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia; September 1997
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Volume 7 DOT/FAA/ND-97/15	Operation Heli-STAR - Cargo Simulation System; Ellen Bass, and Charles Stancil; Georgia Tech Research Institute, Atlanta, Georgia, September 1997
Volume 8 DOT/FAA/ND-97/16	Operation Heli-STAR - Community Involvement; Christine Eberhard and Bobbi Rupp; CommuniQuest, Inc., Manhattan Beach, California; September 1997
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**Atlanta Short-haul Transportation System (ASTS)
Communication/Navigation/Surveillance
Atlanta Communications Experiment (ACE)
Operation Helistar - (HELicopter - Short-haul Transport And Research)
AGATE Flight Systems Communication Work Package 1.4**

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Table of Contents

EXECUTIVE SUMMARY - THE OLYMPIC GAMES, JULY 17TH - AUGUST 4TH, 1996	3
SYNOPSIS OF ATLANTA COMMUNICATIONS EXPERIMENT (ACE).....	4
SYSTEM DESIGN.....	5
IMPLEMENTATION OF CNS GROUND RADIO NETWORK.....	7
OPERATIONS.....	9
RESULTS of ACE	10
CNS-A AIRBORNE SYSTEM REQUIREMENTS	13
CERTIFICATION DOCUMENTS.....	13
Federal Aviation Regulations (FARs)	13
Federal Aviation Administration Advisory Circulars	13
Federal Aviation Administration Technical Standard Orders (TSOs)	14
Radio Technical Commission for Aeronautics Documents	14
ARINC Documents	14
CNS-A AVIONICS REQUIREMENTS.....	15
Software Criticality.....	16
Physical Characteristics	16
System Status - Alert / Warning Indicator Lights	17
Interface Requirements	17
System Assumptions.....	17
GROUND OPERATION SYSTEM DESCRIPTION.....	18
System Check Out.....	19
Message Reliability	20
RADIO FREQUENCY (RF) NETWORK.....	22
Radio Frequency Network Capacity.....	23
CNS/A AIRBORNE EQUIPMENT	26
Navigation Display.....	26
Cockpit Display of Traffic Information - CDTI.....	26
CDTI Traffic Display Icons.....	27
CDTI Controls and Displays.....	27
WEATHER DATALINK	31
Current NWS Data Collection Services.....	32
NWS Planned Improvements	32
Opportunities for Weather Improvements	33
Weather System Definitions.....	33
WeatherLink	34
Broadcast Weather.....	35
EPIREP / Position Report - Air to Ground	39
Text Message.....	42
COCKPIT Display of Weather Data	42
BROADCAST WEATHER PROJECT	44
Broadcast Weather Future Capabilities.....	45
BROAD IMPACT ON U.S. TECHNOLOGY AND KNOWLEDGE BASE.....	49
National Benefits of Weatherlink	50
FUNCTIONAL HAZARD ANALYSIS.....	53

EXECUTIVE SUMMARY - THE OLYMPIC GAMES, JULY 17TH - AUGUST 4TH, 1996

The 1996 Summer Olympic Games held in Atlanta, Georgia was billed as "The largest peace-time event in history". Along with the historical sports drama enacted during the games, other history was made. The Olympic Games provided a unique environment to show that two-way datalink, Global Positioning System, and weather awareness form the basis of the Air Traffic Control System of the 21st Century.

This technology demonstration was designated by the Federal Aviation Administration as the **Communication / Navigation / Surveillance (CNS)** portion of "Atlanta Short-haul Transportation System" (ASTS), later renamed "HeliStar". The NASA AGATE role in the Olympics was conducted under the program name of Atlanta Communications Experiment, ACE. In this document, CNS refers to the ground infrastructure, including telecommunications networks and radio repeater sites, while CNS-A refers to the airborne equipment that communicates with the ground segment.

The functional requirements for CNS included demonstrations of Automatic Dependent Surveillance - Broadcast (**ADS-B**), Cockpit Display of Traffic Information (**CDTI**), Flight Information Service (**FIS**), to include text and graphical weather transmission from ground system to airborne platform, and Air Traffic Management (**ATM**) command and control. These functions form the foundation for "Free Flight," or the ability for each aircraft to choose the optimum flight route based on economy and conditions encountered aloft.

Aircraft operating within the confines of the Olympic venues did so for a variety of reasons. These reasons include security (police, fire, FBI, Secret Service, DOD, Customs), news gathering, Emergency Medical Services, VIP transport, logistical support, air taxi, air cargo, and other Atlanta Committee for the Olympic Games (ACOG) sanctioned purposes. In addition to normal movement of cargo, helicopters were employed in moving perishable or time critical commodities that are normally transported via ground transportation.

Several weeks before the opening ceremonies, the White House issued an edict that would require all aircraft desiring to fly in any of the Olympic venues to be equipped with CNS-A avionics. The FAA was called on to provide avionics, compatible with the now-deployed CNS system. Federal funds were made available and 60 additional CNS-A avionics suites were designed, manufactured, and procured for delivery within 10 days. This procurement was conducted under recently enacted legislation for Federal Aviation Administration procurement rules, and deserves a Gold Medal for the speed in which the Government could act.

Function	Participating Aircraft or Vehicles
Automatic Dependent Surveillance - ADS-B	92 Aircraft, 8 ground vehicles
Cockpit Display of Traffic Information - CDTI	46 Aircraft, 4 ground vehicles
Controller-Pilot DataLink Communication CPDLC	54 Aircraft, 8 ground vehicles
Broadcast Weather	46 Aircraft, 5 ground vehicles, 5 remote sites
Electronic PIREPs - E-PIREPs	6 aircraft, 1 ground vehicle, 4 remote sites

Additional Functions Demonstrated

- Air Traffic Management below RADAR coverage
- Graphical Negotiation of Flight Plan
- Graphical Broadcast of Temporary Flight Restricted Area and other restricted airspace
- Vertical Flight Handling of Time Critical Cargo
- Monitoring of combined security forces - both airborne and ground based
- Surface Tracking of Aircraft at Atlanta Hartsfield Airport for VIP transport
- Air Traffic Management using Airborne Repeaters for beyond line-of-site testing (>250 NM range)
- "ADS-B Contact - cleared into the TFR" added to ATC lexicon
- Allowed the Games to be broadcast "live" with minimal security restrictions

Synopsis of Atlanta Communications Experiment (ACE)

The 1950's era Air Traffic Control System relies upon Very High Frequency Omnidirectional receivers (VOR), Distance Measuring Equipment (DME), and Air Traffic Control Radar Beacon System (ATCRBS) to control the flow of air traffic throughout the National Airspace System (NAS). This system forces aircraft to follow airways that are defined by the physical placement of navigational aids. By following this method, increased costs are incurred by the flight operators due to less efficacy in flight planning, less flexibility in re-routing due to weather delays, and more wait time due to congested airspace surrounding major cities. The Air Transport Association (ATA) has estimated that ATC delays cost the airlines in excess of \$3 billions per year.

With the advent of Global Positioning System, extremely accurate position, time and velocity information can autonomously be derived inside the aircraft. By combining the precise positioning offered by GPS with wireless datalink technology, the pilot may perform flow control, which will enhance ATC system efficiency, enhance aircraft operators economic condition, while at the same time provide increased levels of safety.

The microcosm of activity surrounding the 1996 Olympic Games provided researchers a medium for demonstrating state-of-the art technology in the first large-scale deployment of a prototype communication/ navigation/ surveillance system. At the same time it provided an ideal opportunity for transportation officials to showcase the merits of an integrated transportation system in meeting the operational needs to transport time sensitive goods and provide public safety services in a real-world environment.

Five aeronautical CNS functions using a digital datalink system were chosen for operational flight testing onboard 92 helicopters and fixed wing aircraft participating in the Atlanta Short-Haul Transportation System. These included: GPS-based Automatic Dependent Surveillance, Cockpit Display of Traffic Information, Controller-Pilot Communications, Graphical Weather Information (uplink), and Automated Electronic Pilot Reporting (downlink).

Atlanta provided the first opportunity to demonstrate, in an actual operating environment, key datalink functions which would enhance flight safety and situational awareness for the pilot and an alternative to conventional air traffic control. The knowledge gained from such a large scale deployment will help system designers in development of an national infrastructure where aircraft will be able to navigate autonomously, and provide the transition path to "free-flight" operations.

In advance of the 1996 Olympic Games arriving in Atlanta, city transportation officials and local businesses recognized the need for an effective infrastructure to move time critical goods and provide essential safety services for citizens and the multitude of visitors expected to descend on the city during the games. At the same time, Olympic officials had a simultaneous need to provide security for athletes in and around the Olympic Village and surrounding game venues. From the air, the surface traffic pattern for the Atlanta metro radiates in spoke-like fashion connecting the Atlanta beltway with traffic from three major interstate highways as well as the many local connector roads converging at a central hub, downtown. Coincidentally, the majority of Olympic venues were located downtown at the confluence of the normal traffic flows, which under normal conditions are hectic, let alone the need to accommodate the added multitudes descending on the city to attend the games.

Two years prior to the opening ceremonies, a group known as the Atlanta Vertical Flight Association (AVFA), was created by concerned local businesses (including Federal Express, the United States Parcel Service, Nations Bank, the Atlanta Journal Constitution, Cable Network News, Coca-Cola, the Southern Company, Channel 11 News, Delta Airlines, and Helicopter Association International (HAI)). The group's objective was to jointly pioneer a multimode transportation system that would meet the immediate needs of the Olympics, and to provide a lasting infrastructure for Atlanta, which heretofore had very little vertical flight operations. From this nucleus, a consortium was formed to include the Aviation Security Operations

Committee (ASOC, a key aviation element holding combined security interests within the Atlanta Committee for Olympic Games (ACOG)), the Georgia Emergency Management Agency (GEMA), Georgia Baptist Hospital, Erlanger Medical Center, the Georgia State Patrol, the Georgia National Guard and local police departments. This consortium was rounded out by participation of governmental organizations including the FAA, NASA and FEMA, the involvement of Georgia Tech Research Institute (providing support for heliport logistics and noise monitoring) and Systems Applications International Corp. (contractor to the FAA for logistical support and flight operations). These combined entities became known as the Atlanta Short-Haul Transportation System, or ASTS. Shortly before the games began it was decided that a tactical name was needed to assist two-way radio communications between the helicopters and the ground monitoring centers; hence the salutation "Operation Heli-STAR" was contrived (HELicopter - Short-haul Transport Aviation Research) as nearly all flight operations involved helicopters.

Plans were made by ASTS for deployment of a network of nine new heliports at strategic downtown locations and improvements to existing facilities at the three primary Atlanta airfields, Hartsfield Atlanta International, DeKalb-Peachtree, and Fulton County-Charlie Brown. An interconnecting route structure was established linking the landing zones. From the start, officials were cognizant of the community's possible reaction to the noise generated by a bevy of helicopters flying over a city unaccustomed to any significant level of flight activity. To counteract complaints, helicopter traffic routes were designed to follow interstate highways where possible and approaches to new heliports were situated over industrial or unpopulated areas to the extent possible. Also detailed operating criteria were developed with consideration for the surrounding neighborhoods and flight safety.

It quickly became apparent that a communications, navigation and surveillance (CNS) system was needed to communicate with the aircrew as well as provide a capability to monitor the location of the helicopters while carrying out their missions. Such capability was especially needed by dispatchers and pilots for those helicopters in the package delivery service operating into the newly deployed heliports. Most of these new landing zones were capable of accommodating a single helicopter on the pad and had no ancillary parking space. Similarly, security officials desired the capability to monitor the location of all participating aircraft as well as their resources operating in and around the Olympic venues, in order to effectively carry out coordination activities in the event of any threat to disrupt the games. With limited technical resources capable of handling the special needs of this project, the ASTS consortium tapped the expertise of another newly formed consortium - the Advanced General Aviation Technology Experiment (AGATE) Alliance. The needed expertise would come from resources within AGATE's membership.

The primary AGATE corporate participants were ARNAV Systems Inc., Harris Corporation, Pan AM Systems, Digital Equipment Corp., AvroTec, Inc., Terra Corp. (now Trimble Navigation), ARINC Inc., NavRadio Corp., Cirrus Design Corp. and Small Aircraft Manufacturing Association (SAMA). CNS project oversight and logistical support came from NASA's Langley Research Center and the FAA's Langley Engineering Field Office. Funding and on-site logistical primary support for the effort came from the FAA through the Office of General Aviation and Vertical Flight, which staffed the effort for the duration of the games.

System Design

The initial criteria identified by the ASTS partners was the need to provide communications, navigation, and surveillance services for approximately fifty helicopters to support security and surveillance operations, emergency services, and cargo hauling operations for the duration of the Olympics. After surveying the primary ASTS requirements, design of the CNS system was undertaken with the secondary consideration for the technical development nature of the AGATE program's charter. Hence, the attempt was made to meet a mutually agreeable set of objectives during accomplishment of the project. It was with this understanding that the CNS system to be delivered would be an engineering prototype assembled from commercial off-the-shelf hardware, and integrated into an operable system capable of handling the entire ASTS requirement.

Five primary CNS functions were jointly identified by ASTA and AGATE leaders as necessary to support the wide range of helicopter operations. These consisted of:

- Automatic Dependent Surveillance-Broadcast (ADS-B)
- Cockpit Display of Traffic Information (CDTI)
- Weather Information uplink (Weather Broadcast)
- Controller/Pilot Datalink Communications (CPDLC)
- Automated Electronic Pilot Report transmission (E-PIREPs)

These functions were given weighted merit during system design deliberations as to their utility for meeting ASTS needs as well as providing technical insight to research issues identified by AGATE partners. The large scale deployment of aircraft in an operational demonstration surrounded the Olympics, afforded the unique opportunity to exploit the capabilities this new technology and address issues of concern in the development of a national free-flight system.

Important and common to all operations was the requirement for ground personnel to track and monitor the location of participating aircraft as they performed their individual missions. Participating helicopters would be flying in generally unrestricted airspace as most of the airspace overlying the Olympic Village and downtown venues was outside or below the Class-B airspace for Hartsfield Atlanta International (ATL) Airport. All flight to/from Fulton County-Charlie Brown (FTY) and DeKalb-Peachtree (PDK) general aviation airports were inside of Class D airspace, as was most of the route structure. Complicating the surveillance requirement was the fact that the helicopters would be flying below radar coverage from the two nearby air traffic surveillance radars, located at ATL (seven miles south) and Dobbins Air Force Base (10 miles northwest). Tracking of the helicopters would be needed beginning at the surface up to approximately 1500 feet for the typical mission profile whereas conventional radar only allowed tracking down to approximately 1800-2000 feet over the city and major venues.

It was decided that a broadcast form of automatic dependent surveillance (ADS-B) would be used to transmit position information from the aircraft to the ground monitoring stations. This technique involves an aircraft broadcasting its position, obtained from an independent onboard navigation system, to receivers on the ground via digital datalink. Global Positioning Satellite (GPS) data was used as the airborne navigation information source. Individual aircraft position coordinates are subsequently displayed on a computer screen in graphic form much like a conventional radar display.

CNS-A Equipment definitions:

Multi-Function Display (MFD): A device used for the graphical display of information in the cockpit. Normal display functions include the depiction of the aircraft in relation to airports, nav aids, victor airways, man-made and terrain obstacles, and other geographical features, as well as the graphical depiction of weather products.

ADLP - Airborne DataLink Processor - the aircraft equipment receives weather information from the ground and transmits collected atmospheric raw data from the aircraft. The airborne transceiver determines frequency activity, atmospheric noise, and distance from ground stations, allowing appropriate communication parameters with the ground stations.

Electronic Pilot Report (EPIREP): An EPIREP is a pilot report that is automatically transmitted from the aircraft, without pilot intervention. The elements of the EPIREP are aircraft ID, aircraft type, latitude, longitude, altitude, outside air temperature, humidity, and winds aloft. These data elements are collected using Global Positioning System (GPS) sensors and transducers on the aircraft, formatted by the ADLP, and transmitted to the ground at regular intervals.

Inherent to the design of a broadcast datalink system for air/ground ADS messaging was the capability for aircraft equipped with a graphical display to also receive the position information from participating

aircraft. Hence it was decided to demonstrate Cockpit Display of Traffic Information (CDTI) with as many aircraft as could accommodate a multifunction display (MFD) onboard.

For those aircraft equipped with a MFD the means was at hand for displaying weather information to the cockpit. NEXRAD weather radar and airport surface observations were coded and processed by the ground datalink station for broadcast to the aircraft on a periodic basis. Approximately every five minutes a new meteorological data set would be automatically transmitted for reception by equipped aircraft.

The opportunity afforded by those aircraft equipped with a MFD to receive and send datalink messages permitted additional testing of several concepts aimed at enhancing controller/pilot communications. Through the use of keyboards and interactive "touch screen" displays at the ground monitoring stations, operators could send free text or prepared messages to the cockpit. This would allow ground mission managers an alternate means to communicate with aircraft in flight, as two-way radio frequencies were limited and congested.

Finally, the technology capable of providing the preceding functions also provided the basis to demonstrate a new capability for automatic transmission of Electronically-generated Pilot Reports (EPIREPs). In a manner similar to airlines downlinking information from air-data computers, ASTS-equipped aircraft could downlink pseudo meteorological data. In a more mature application, temperature, dew point, winds and icing information could be used by National Weather Service computer models to enhance the accuracy of current forecasts and help pave the way towards shorter term forecasts.

Implementation of CNS Ground Radio Network

DeKalb-PeachTree Tower

ARNAV and SAIC personnel installed the CNS datalink antenna on top of the PeachTree DeKalb Airport Federal Aviation Administration Tower. RG-8 co-ax cable was routed 40 feet through insulated conduit into the tower at the cab level. The CNS ground receiver was set to be a "fixed repeater". Serial port C was enabled so that if desired, a live feed of all datalink activity can be displayed to tower personnel.

Hartsfield Atlanta International Tower

ARNAV and SAIC personnel installed the CNS datalink antenna on a lightning protected pole on top of the Atlanta International Airport FAA tower. RG-8 cable was routed 50 feet through insulated conduit into the 12th level of the Tower structure. The CNS ground receiver was set to be a "fixed repeater". Serial port C was enabled so that if desired, a live feed of all datalink activity can be displayed to tower personnel, two floors above the CNS ground equipment. A preliminary check was performed to determine the difficulty of routing the data the extra two floors up to the tower personnel. It was determined that this would be possible with minimal effort (less than 4 hours to rout serial communication line and to set up PC workstation).

Georgia Tech Research Institute

ARNAV and SAIC personnel installed the CNS datalink antenna on a pole on top of the Georgia Tech Research above Building 3 of the GTRI complex adjacent to Dobbins AFB. 100 feet of RG-8 co-ax was routed inside the building to the CNS ground receiver. The CNS ground receiver was then connected to the ARNAV Network Control Terminal through 200 feet of shielded twisted pair cable routed through the ceiling tiles to the cubical area that served as the command center for the POC.

ARNAV Network Control Station

The ARNAV Network Control Station was set up in an office cubicle in Building 3 of the GTRI complex in Marietta, GA, adjacent to Dobbins AFB. From this location, status of the entire network was monitored. All messages to the aircraft were generated from this workstation. Received messages from the aircraft were also stored on this work station. A backup Network Control Station was established in an adjacent Command Center. This backup Control Station was required to fulfill commitments made to the White House for fail-safe operations.

Harris Ground Operation System

The Harris Ground Operation System was set up in an office cubicle in Building 3 of the GTRI complex in Marietta, GA, adjacent to Dobbins AFB. The interface between the Harris and ARNAV Network Control Station was established through a 9600 baud serial connection. The RF modem was used to interface the ADS processor with another Harris-provided PC (running under Linex) which served to represent the Georgia Tech Research Institute (GTRI) data processing system.

The Harris prototype system consists of a single-thread ADS processor, implemented on a PC/DOS platform; a high-resolution DEC Alpha geographic display; an auxiliary PC controller information display system (CIDS); and a data communication system consisting of multiple RS-232 modems and one spread-spectrum L-band RF modem.

Implementation and deployment of the system was predicated on close cooperation and interaction of the primary industry participants lending their individual expertise to the endeavor. Two operational tests were conducted of the system, one in October 1995 to prove to ASTS personnel that the concept was realizable, and a second in February 1996 to demonstrate all the required capabilities.

Three ground monitoring stations were deployed to handle the varied ASTS missions. The first, referred to as the Traffic Advisory Center (TAC) was located at Dobbins Air Force Base and used by security officials and air traffic controllers to monitor and track aircraft entering restricted airspace. The TAC employed two ADS situation displays for redundancy and were programmed to show the position of all aircraft with compatible CNS avionics. The 20-inch color displays showed the position of all participating aircraft with small icons annotated with identification tags much like ATC radar. Each console position was equipped with a keyboard and "touch-screen" interactive display for composing two-way digital datalink messages which could be sent to the aircraft.

The second ground monitoring station was located at GTRI, outside the Dobbins gate, and used for dispatch and monitoring of the helicopters used in the trial cargo hauling operation. Referred to as the Project Operations Center (POC), this facility was accessible to persons wanting to observe the system and view non-secure operations. Traffic shown on the POC displays was filtered to show only non-security flight operations. Requests for datalink communications with participating aircraft were forwarded to the TAC for transmission.

A third ground display was located at GEMA's Emergency Operations Center (EOC) in downtown Atlanta, where the combined emergency response teams were represented. This display showed the full complement of traffic (i.e. secure and non-secure) as the TAC.

The POC location was chosen as the primary site for network control and for reception of ADS messages from aircraft because of its higher elevation. From there, aircraft position data was sent over dedicated telephone lines to the TAC which hosted the primary display processor being adjacent to the more critical tracking displays used by security personnel. A backup receiver was installed at the TAC in case of failure of the primary station. Processed data was sent back over phone lines to the POC for display and, similarly, to the EOC at GEMA.

Each airborne datalink unit had the capability of being commanded from the ground to act as a repeater, similar to those on the ground, for relay of signals from aircraft beyond the reception range of the ground

stations. Frequently, one of the blimps operated by the Atlanta Police Department and stationed over the Olympic Village was used as the sole repeater since it had a commanding view of all participating aircraft. This served to reduce the number of messages being repeated over the RF network allowing for faster update rates during times of peak activity. Output RF power of the airborne units could likewise be controlled remotely from the ground, allowing the ARNAV Network Control Station to set priority reporting schemes for the airborne assets.

The typical avionics suite consisted of three pieces of hardware: a solid-state liquid crystal multi-function display (MFD), an integrated GPS receiver and datalink transceiver unit, and the associated airborne processor. The pilot was able to access various display modes from an on-screen menu commanded by a series of buttons on each side of the display. The CDTI mode allowed the ADS-B function of participating aircraft to show as targets as icons on the screen with an adjustable scale of approximately 5 to 19 miles in range. A display format was used similar to the Threat Avoidance and Collision Alert Warning System (TCAS) the airlines use. A moving map mode was implemented which had an adjustable ranges from 5 nautical miles to 150 nautical miles, and showed ground obstructions and special use airspace. The graphic weather display showed NEXRAD radar data in block cells representative of the highest level of reflectivity.

OPERATIONS

The initial requirement to meet the anticipated needs of the Atlanta Short-Haul Transportation System was to equip up to 50 helicopters with the CNS-A equipment. All participating aircraft would establish voice contact with the Traffic Advisory Center for target identification and ADS monitoring. Those helicopters conducting cargo operations would take further instruction from the Project Operations Center after their initial contact with the TAC. Cargo operations alone were planned to consume over 1400 hours of flight time and carry 1.5 million pounds of time-sensitive cargo for ASTS participants over the 17 days of the Olympic Games.

From the onset the security interests of the Atlanta Committee for the Olympic Games pressed for a flight restricted area encompassing all of the city and Olympic venues. The FAA recognized this would place restrictions on a great deal of airspace heretofore designated unrestricted, hence deny many pilots the right to fly. A compromise was reached whereby airspace would be temporarily restricted over the Olympic village and the active game venues. Temporary Flight Restricted areas were charted, and disseminated by special Notice To Airmen (NOTAM). Mandatory aircrew training was required prior to operations therein. Two sessions of training were established for pilots, one conducted by the FAA's Southern Region Headquarters oriented towards operations permitted within the TFRs, and a second, conducted by ASTS personnel on the operation of the CNS equipment and ASTS operating procedures.

Several weeks before the opening ceremonies, the White House issued an edict that would require all aircraft desiring to fly in any of the Olympic venues to be equipped with a CNS-A avionics. The FAA was called on to provide avionics, compatible with the now-deployed CNS system. Federal funds were made available and 60 additional CNS avionics suites were built under a letter of national exigency. These units were designed to be portable including self contained batteries and window mount antennas, capable of being carried onboard different aircraft. The additional units enhanced the research aspects of the exercise by providing the opportunity to track a greater number of aircraft than otherwise would have been possible.

Operations at the Traffic Advisory Center were conducted on a 24-hour basis under the purview of a team of 12 Air Traffic Control Specialists. These personnel had the primary responsibility for coordinating airspace use with security officials and effecting the orderly conduct of air traffic in and around the TFRs. Much credit is due this highly experienced and dedicated troop for maintaining smooth operations throughout the duration of the games. While two-way radio contact with the TAC was required of all aircraft while operating in the TFRs, it was the ADS-B situation displays that became the primary tool at

their disposal to track aircraft. TAC operations were augmented with "DBRITE" radar displays remoted from the Dobbins surveillance radar which provided primary and beacon target traffic down to 1800 feet. However, only the ADS-B displays continued to provide traffic position information to the surface.

The Project Operations Center was manned by personnel from ARNAV, the FAA, and GTRI who provided oversight for all cargo operations. Smooth operation of this mission was critical for an effective demonstration of the ASTS concept to the satisfaction of the primary business partners. Cargo flights were conducted by a fleet of eight dedicated helicopters based at Peachtree DeKalb airport and operating over specified routes between the newly deployed heliports. The ADS-B situation displays were critical to this operation to keep track of the movement of time-critical goods being carried. ADS-B also served to provide timely response to noise complaints from the community -quite often exonerating ASTS participating pilots. Many unrelated helicopter operations were being conducted in and around Atlanta other than those specifically under the purview of ASTS.

A total of 92 aircraft were equipped with compatible CNS avionics and were tracked over the period of operations. These included the expected security, law enforcement and emergency service helicopters as well as eight dedicated to the cargo hauling operation.

Aircraft installations continued up to and during the games as needs continued to be identified. Aircraft installations consisted of either permanently installed systems with outside mounted antennas, as originally planned, or outfitted with one of the portable units typically operating with GPS and datalink antennas placed in the window. Differential GPS was not used as it was deemed too expensive and time consuming a proposition for a two-week event.

Three blimps were similarly equipped and one was usually hovering over the Olympic Village at all times. The CNS unit on this aircraft was often used as an airborne repeater which greatly extended the range participating aircraft could be tracked.

Results of ACE

The experience gained throughout the Olympics exercise will go far to benefit research and development efforts leading to a new generation of cooperative air traffic control and the systems needed for a free-flight environment. Although most of the ASTS operations were flown by helicopters, the analysis and benefits are expected to apply both general aviation and air carrier aircraft as well. This exercise comprised the largest single demonstration and test of an integrated CNS system to date in the U.S. It successfully demonstrated the multiple datalink functions (ADS-B, CDTI, CPDLC, and weather up-and-downlink) needed for Free-Flight. Unlike other demonstrations, this system used a VHF datalink system for datalink communications between the ground system and avionics. The AGATE partners provided a prototype system that was effectively used by pilots and controllers in the conduct of actual mission operations while serving research interests at the same time.

Notwithstanding the White House mandate at the eleventh hour requiring around the clock operations and all aircraft entering the Flight restricted zones to be CNS equipped, all parties rallied together to pull off a smooth operation. The multi-mission aspects of the effort involved the close cooperation of security officials, law enforcement authorities, air traffic control, cargo haulers and the associated logistics and support personnel.

One of primary missions for the CNS system was to provide a means for tracking aircraft in and around the Olympic village and venues for security interests. The CNS-A systems was installed in Customs security forces that patrolled the airspace for the duration of the games. These security forces had "*Posse Comatatus*" status, meaning that they had deadly force options at their disposal. A DataLinked feed of all tracked vehicles was given to the Orion P3's that used side-looking RADAR as they patrolled the Airspace from a stand-off position 70 to 100 nautical miles south of Atlanta. This feed of "known good-guys" was correlated with the P3's AWACS Radar. The Customs Blackhawk helicopters were used for in-

close tactical maneuvers, while the Citation fixed wings formed Top Cover Command and Control for the security operations.

The ground situation displays at the Traffic Advisory Center were manned continuously by the air traffic controllers beginning the week prior to opening ceremonies and concluding two days after the close of the games. Since the primary situation displays were designed with input from the air traffic control specialists, the equipment was easy to operate and comprehend for ATC use. ADS-B was the primary means of tracking aircraft below the coverage of the Dobbins radar, which was remoted to a DBRITE display located above the ADS console. Data tags on the ADS traffic display, similar to tags on actual radar displays, greatly aided the controllers in identifying individual aircraft. Tactical call signs were used by controllers for addressing aircraft for positive identification as they became airborne. This call sign was easily added to the display database for annotating the ADS target icon seen on the display.

Another mission of ASTS was that of providing cargo-hauling operations of time critical goods. This operation required a similar means of tracking and dispatch communications, and was dispatched from the Project Operations Center in a likewise successful manner, allowing helicopters to carry out their route specific operations in an expeditious manner. During one flight, the FAA received a report that one of the cargo operators had violated airspace over the Olympic Stadium. FAA personnel were able to determine the exact position of the aircraft's flightpath by examining the recorded position data. This data was used to exonerate the pilot, as the system proved that the aircraft in question had followed prescribed routes. In another instance, the Network Control Center was able to positively identify a news gathering helicopter that had violated Temporary Flight Restriction airspace, and to supply the FAA with printed documentation that was used for disciplinary action. These incidents were both processed within 2 hours of the alleged violation.

From an overall systems operation perspective, the airborne and ground equipment worked to the satisfaction of the AGATE designers and users operating without major glitches once placed in service and throughout the four week period surrounding the games. The only notable downtime was attributed to a telephone cable being dug up that carried data from the network control station at the POC to the ground display processor at the TAC and a broken connector on a backup display at the TAC. This type of reliability was no small feat for a prototype system. In anticipation of potential problems, personnel from the equipment providers were available, either on site or on call, around the clock, to handle any discrepancies with the ground displays or avionics installations. Fortunately, they were few times that their services were needed.

The system experience gained by researchers provided the ability to study how ADS-B technology would perform in meeting surveillance needs in lieu of radar. Also the capability ADS affords for air-to-air CDTI was of interest, being seen as an important step in the movement towards a free-flight operating environment.

One of the parameters of key interest with respect to both issues was the timeliness of aircraft position update rates. Aircraft position update rates were initially set to be similar to that of an airport surveillance radar, about every five seconds. In actuality, update rates as viewed on the ground situation displays were noted to vary over a range from the nominal five-seconds to approximately thirteen seconds when multiple targets were being tracked. The transmission of weather datalink messages and the occasional need to effect configuration changes to the ground-based repeater network also served to slow update rates since the weather information and control commands were issued on the same frequency as aircraft position reports. The adaptive nature of the transmission scheme in the communication system design allowed the timing of each aircraft's transmission to occur on a more or less random basis in order to reduce simultaneous transmissions hence causing further delays as the aircraft have to rebroadcast their position. Certain helicopters had their transmission rate specifically set to provide once per second updates to accommodate the special needs of the community noise gathering operation to permit correlation with data being collected by ground noise monitors.

Observations made at the ground operating consoles located at the Traffic Advisory Center and the POC revealed that most of the discrepancies in aircraft position being lost as reported by the air traffic control specialists (at the TAC) or by operators (at the POC) revolved around the reduced ability of the portable units to maintain track as compared to the permanent aircraft installations. The algorithms designed into the ground display required receipt of a valid position update within a thirty second period or the color of the icon would change - from white to red - indicating an unreliable position and not to be trusted.

The initial ASTS helicopters had GPS and datalink antennas permanently installed on the outside of the aircraft in optimum positions. Since the portable CNS boxes were mandated at a late date, time did not permit an optimum mounting of the antennas on the exterior. As a result, most of the portable installations had the GPS antenna placed on the glare screen or taped in a window which greatly reduced visibility of the satellites. GPS requires a minimum of 3 satellites in view to render position. With only 12 satellites visible in the hemisphere, any installation having a limited view of the sky would tend to yield a low probability of calculating aircraft position for transmission to the ground. Likewise, the datalink antenna was often sub-optimally installed, typically affixed to a side window, reducing the probability of reliably interacting with the primary ground receiver or repeater sites. This was especially noticeable when an aircraft was flying in areas outside of the triangular layout of receivers and the antenna oriented away from the receiver sites. The combined result of internally mounted antennas was a greatly reduced probability of receiving a valid update position within the time window needed to keep the target active on the situation display.

Working distances for the ADS-B function turned out to be surprisingly good, covering the greater Atlanta area with reliable coverage to the surface of all the designated landing zones, aircraft antenna installation notwithstanding. Tracking is theoretically determined to be line of sight from the aircraft to one of the ground repeater/receiver locations. Two fixed wing aircraft who happened to be equipped with complementary CNS hardware reported tracking from a distance of approximately 150 miles while inbound to Atlanta.

Aircraft capabilities were enhanced if they were equipped with an optional multifunction display (MFD) which upon receipt of the ADS-B broadcast from other aircraft permitted viewing of traffic (i.e. CDTI) and display of uplinked weather information. Of approximately 40 permanently installed systems only about 25 included the multifunction display option. The portable CNS boxes were capable of connecting to a MFD (or laptop computer) but only a couple operators took advantage of that option.

As with the ground situation displays, position updates for the CDTI function were variable in timeliness of receipt of information. The display orientation when the aircraft were making turns was also a factor in acquiring targets. This was in part due to the MFD having the capability of displaying a number of background options such as waypoints, airports and ground obstructions. With fewer options selected, the MFD updated reasonably well for displaying traffic. Since helicopters were flying low and on short missions, display of the weather was not a highly used option as it would be for aircraft traveling longer distances at higher altitudes.

Pilots were asked to fill out questionnaires at the conclusion of each daily mission. These data will be included in the detailed analysis which is currently underway by the FAA.

One of the immediate research benefits of the ASTS operation will be to furnish AGATE, the FAA, and other interested parties with hard data on which to base designs for future deployment of systems that lead to free flight operations that are interoperable and cost-effective for general aviation and air carrier aircraft. It will translate into aircraft that are easier to fly and able participate in a cooperative manner with systems designed for air carrier operations.

AGATE's interest is oriented at designing the needed guidelines, standards and certification methods needed to bring a new generation of aircraft to market. This aircraft must have avionics suite that is low-

cost and interoperational with RTCA standards which heretofore been primarily designed around air transport needs.

In the path to overall revitalization of the general aviation industry (and enhancements to the air carrier fleet), there will be the retrofitting of the current fleet of aircraft with systems that provide an added margin of safety to operations by providing graphical weather uplinks where none exist today. With the advent of ADS-B implementation comes the opportunity for augmented traffic situation awareness in the cockpit. Deployment of Datalink technology on a wide scale will also provide the nucleus for enhanced pilot controller communications in concert with FAA modernization plans.

Further analysis of the data, consisting primarily of the technical issues surrounding datalink system loading and signal propagation, will provide needed input to upcoming development of systems standards and programs currently being worked.

CNS-A Airborne SYSTEM Requirements

Certification Documents

The CNS/A equipment was designed using guidelines from the following documents, and was awarded Supplemental Type Certification from the New York Aircraft Certification Office (ACO) three weeks before the opening ceremonies.

Federal Aviation Regulations (FARs)

The following FARs are to be considered part of this specification. Compliance with their requirements is necessary to the design of a certifiable product.

- Part 21, "Certification Procedures for Products and Parts."
- Part 23, "Normal Utility and Acrobatic Category Aircraft (under 12,500 pounds)."
- Part 25, "Transport Category Aircraft."
- Part 27, "Normal Category Rotorcraft."
- Part 29, "Transport Category Rotorcraft."
- Part 43, "Maintenance, Preventative Maintenance Rebuilding and Alteration."
- Part 91, "General Operating and Flight Rules."
- Part 121, "Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft."
- Part 135, "Air Taxi Operators and Commercial Operators."

Federal Aviation Administration Advisory Circulars

The following FAA Advisory Circulars are to be considered part of this specification. These Advisory Circulars have been used as guidelines.

- AC No. 21-16C, "Radio Technical Commission for Aeronautics Document DO-160C."
- AC No. 90-82, "Random Area Navigation Routes."
- AC No. 90-45A, "Approval of Area Navigation Systems For Use in the U.S. National Airspace System."
- AC No. 90-79, "Recommended Practices and Procedures For the Use of Electronic Long-Range Navigation Equipment."
- AC No. 20-130, "Airworthiness Approval of Multi-Sensor Navigation Systems for use in the U.S. National Airspace System and Alaska."

- AC No. 25-15, "Approval of Flight Management Systems in Transport Category Airplanes."

Federal Aviation Administration Technical Standard Orders (TSOs)

The following TSOs are to be considered part of this specification. Compliance with their test standards is necessary to the design of a certifiable product.

- TSO-C129, "Airborne Supplemental Navigation Equipment using the Global Positioning System."
- TSO-C113, "Airborne Multipurpose Electronic Display"
- TSO-C115a, "Airborne Area Navigation Equipment Using Multi - Sensor Inputs"
- SAE AS-8034, "Minimum Performance Standard for Airborne Multipurpose Electronic Display"
- SAE ARP 1068B, "Flight Deck Instrumentation and Display Design Objectives for Transport Aircraft"
- ARINC 725-2, "Electronic Flight Instruments"
- AC-20-136, "Protection of Aircraft Electrical/Electronic System against the Indirect Effect of Lightning"
- AC-20-130A, "Airworthiness approval of Navigation or Flight Management Systems integrating multiple navigation sensors"

Radio Technical Commission for Aeronautics Documents

The following RTCA documents are to be considered part of this specification. Compliance with their minimum performance test standards is necessary to the design of a certifiable product.

- RTCA/DO-160C, "Environmental Conditions and Test Procedures for Airborne Equipment."
- RTCA/DO-178B, "Software Considerations in Airborne Systems and Equipment Certification."
- RTCA/DO-200, "Preparation, Verification and Distribution of User-Selectable Navigation Data Bases."
- RTCA/DO-201, "User Recommendations for Aeronautical Information Services."
- RTCA/DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)."
- RTCA/DO-200, "Preparation, Verification and Distribution of User-Selectable Navigation Data Bases"

ARINC Documents

Specific paragraphs of the following ARINC documents as referenced by this specification are to be considered part of this specification.

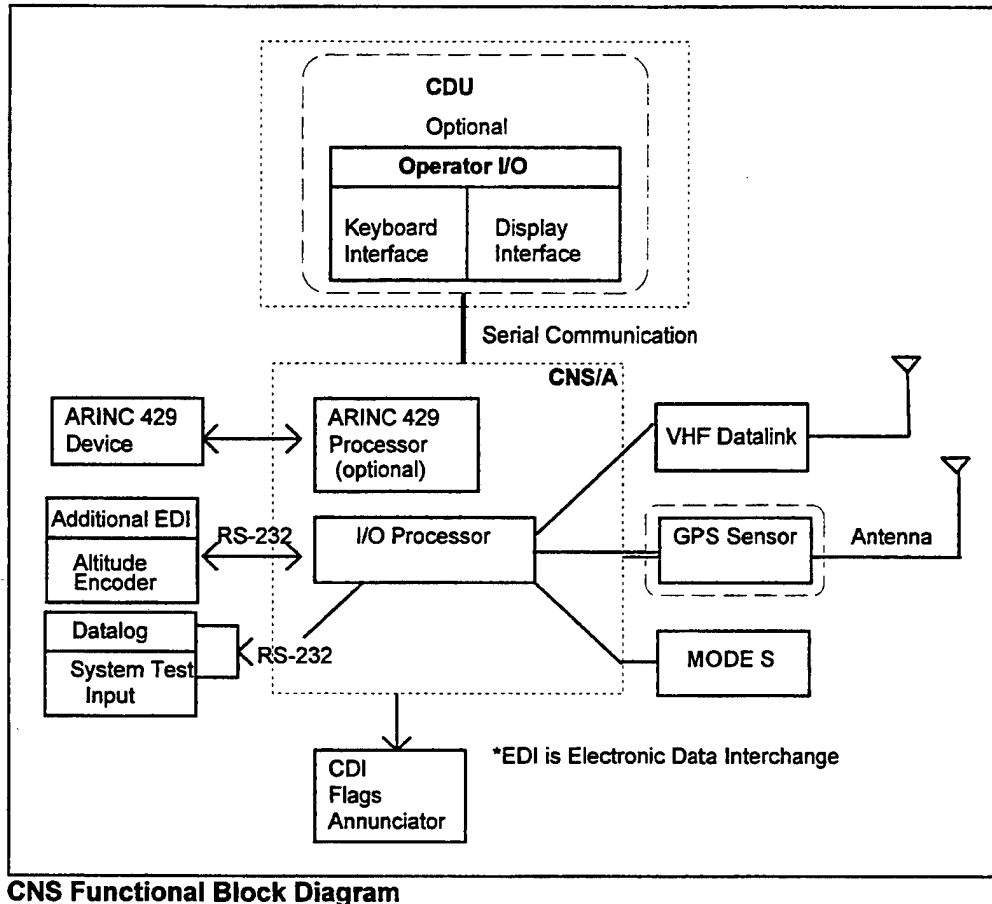
- ARINC 404A, "Air Transport Equipment Cases and Racking."
- ARINC 410, "Mark 2 Standard Frequency Selection System."
- ARINC 424.9 "Navigation System Data Base."
- ARINC 429-12, "Mark 33 Digital Information Transfer System (DITS)."
- ARINC 547, "Airborne VHF Navigation Receiver."
- ARINC 601, "Control/Display Interfaces."
- ARINC 607, "Design Guidance For Avionics Equipment."

CNS-A avionics Requirements

Elements of the CNS/A may be designed in a modular fashion to fulfill the functional requirements. These elements will provide the following minimum functional capabilities:

1. The CNS/A shall operate in the current National Airspace system in any general aviation aircraft; from an electrically equipped J-3 Cub, to helicopters, to regional airliners.
2. The Global Positioning System receiver portion of the CNS/A shall be TSO C129-C1 (A1) certifiable (non-precision approach), or have a suitable interface for an existing certified Global Positioning System receiver.
3. The CNS/A I/O processor must contain protocol formatting so that it can interface with Mode S transponders operating on 1030/1090 MHz frequency, using the 112-bit extended squitter transmit, 56 bit squitter receive. This formatted message must be compatible with the ICAO adopted Global Positioning System / Automatic Dependent Surveillance Broadcast Mode (ADS-B). The CNS/A Mode S squitter protocol must also accept the 8 closest aircraft when transmitted from ground based TIS Mode S sensors. The I/O processor will then pass the closest aircraft to the CDU to provide inflight display of other aircraft from ground and air sources and at various pilot selectable ranges. This technique is similar to the TCAS traffic advisory function. The CNS/A automatic dependent surveillance is provided by the broadcast of GPS position via Mode S data link for air traffic purposes and via other data links for personal use.
4. The I/O processor will format messages and interface to Very High Frequency (VHF), UHF, and CCITT protocols (cell phone). The protocol for this will follow the RTCA 169, working group 3 formats for broadcast messages, both for airborne and ground stations. Commercial communications will be accommodated through VHF, UHF, and cellular phone capability for personal data link usage and for providing expanded weather and flight planning services that can be purchased commercially.
5. The CNS/A will collect and process electronic pilot reporting (EPIREP) data, reading the aircraft sensors and formatting the datalink output to the appropriate protocol, and to relay them to ground stations at a minimum of once per 10 minute interval. The CNS/A electronic PIREP will provide the users, Federal Aviation Administration, and the National Weather Service a real time assessment of the flight weather and without pilot interference or workload.
6. The Control Display Unit (CDU) will have an optional control unit and display device that have been "pilot factored" for each type aircraft and operation. The design of the CNS/A system will provide the pilot with a system that is as autonomous as possible, not labor intensive, and designed from the pilot's perspective. Automated databases for most functions will be provided as part of the CDU. However, with the built in data link capability, updating could be simplified using scheduled ground station updates and on board pilot update approval protocols.
7. The CNS/A will have sensor inputs that will simulate Emergency Locator Transmitter (ELT) features, to include both G-switches and pilot controlled

switching. When the ELT function has been enabled on the airborne platform, the I/O processor will give priority handling of the message formatting. When the ground station receives an ELS message, it will immediately notify the ground operator in both visual and aural queues.



Software Criticality

Because the determination of a geographic position is identified as essential software criticality, all components of software in the CNS/A are considered essential criticality.

Software Partitioning

The control program suite of the CNS/A system shall be comprised of three software configuration items (SCIs):

- The CNS/A I/O Processor Control Program which shall control I/O processes and drive external annunciators.
- The Global Positioning System Sensor Control Program
- The CNS/A ARINC 429 Processor Control Program

Physical Characteristics - Environmental Testing

The CNS/A operator interface shall be constructed to pass environmental tests as defined by DO-160C, at levels consistent with part 91, part 135, and part 121 installed aircraft equipment.

System Status - Alert / Warning Indicator Lights

The CNS/A shall provide system and/or status indicators for the following conditions

- a) inadequate or invalid navigation signals or sources
- b) equipment failures
- c) datalink transmission in progress

The status, alert and warning indicator lights will be placed in the pilots primary field of view, as defined by TSO's as appropriate.

Interface Requirements

- 1) There shall be a minimum of three serial communication I/O ports on the CNS/A, one dedicated to communication with the CDU and one dedicated to communication with external devices such as Air Data and Altitude Encoder, and one that is used for datalink message routing. At least one dedicated communication port must be provided for each datalink type provided (Mode S, VHF, UHF). Multiplexing of data ports is permissible for datalinks considered non-critical to flight, i.e. business communications.
- 2) The CNS/A shall be responsible for providing position information to the following:
 - the operator interface (display, keyboard, system status indicators)
 - All DataLink processes
 - Emergency Locator Systems
 - the ARINC 429 I/O interface
 - the internal GPS sensor for initialization
 - optional external sensors through the serial communication port
- 3) The CNS/A shall provide drive signals for the following external displays:
 - the external NAV FLAG based on inability to meet IFR accuracy requirements (conforms to ARINC 547 paragraph 3.16)
 - the external panel annunciators
 - the external To/From indicator (conforms to ARINC 547 paragraph 3.18)
 - the external directional reference system (CDI) (conforms to ARINC 574 paragraph 3.15)
 - the Super Flag (conforms to ARINC 410 paragraphs 3.12 - 3.14 and ARINC 547 paragraph 3.26.1)
- 4) The ARINC 429 I/O processor shall receive position information, and provide this information to external 429 sensors.

System Assumptions

The following assumptions shall be considered in the representation of the data handled by the CNS/A described herein:

- Distances shall be computed in feet and nautical miles
- Altitude shall be computed in meters
- Groundspeed shall be computed in knots.
- Bearing shall be computed in both magnetic and true degrees.
- Winds direction shall be computed in degrees true.

- Bearing and radial shall be displayed as integers from 1 to 360; if the operator enters 0, the CNS/A will compute as if the user entered 360.
- The WGS-84 coordinate system will be used for all position reference
- Degrees latitude shall be in the range as an integer from 00 to 89.
- Degrees longitude shall be in the range as an integer from 000 to 179.
- Minutes associated with latitude/longitude shall be a fixed length number from 00.000 to 59.999, always maintaining at least three digits of decimal representation.

Ground operation System Description

The ground operation terminal will perform (as a minimum) the following functions:

1. Ground monitoring of aircraft movement, displayed in real time on a high resolution display device. The user interface will be both mouse and keyboard driven, with standard ATC short code support so that messages may be constructed with minimum keystrokes. For example, if the operator wishes to send a message to an aircraft, a mouse point and click will select the aircraft to receive the message. By typing "TR 260 FT", the computer should reconstruct the message to display "AGATE 199, Turn right heading 260 as needed for traffic spacing". After validation of message content, another mouse click will send the message to the intended recipient.
2. Data recording of all aircraft positions and messages sent and received. A minimum data set for position report will include Aircraft ID, latitude, longitude, altitude, time, and aircraft status message. A facility must be provided to replay any time period for later analysis, or to export the recorded data to comma delimited ASCII files so that post Olympic analysis of aircraft movement may be performed.
3. Two-way ad hoc freeform text message between ground station and any datalink user. There must be an option to encrypt/decrypt messages for security reasons.
4. Aircraft dispatch management from ground station. This function could call up a pre-registered flightplan, display flightplan on display, and ask operator the enable flight plan. Once enabled, the datalink message of confirmation would automatically be sent to the aircraft.
5. Weather Information uplink of weather radar images, Sequence reports (SA) within a 150 nautical mile radius of Atlanta, Pilot reports (including electronic pilot reports) within 150 nautical miles of Atlanta, AIRMETS and SIGMETS that affect area within 150 nautical miles of Atlanta.
6. Flight operational communications
7. Administrative communications (passenger phone, fax, data)
8. Collection, validation, recording and dissemination of EPiREP data.
9. Data analysis and system monitoring during operations

CNS System Validation

After all ground sites were installed, an operation systems test was conducted. A rental car was equipped with a CNS/A datalink, and was used for RF site determination throughout the greater Atlanta metropolitan area. This CNS/A was configured to send out a position report every four seconds as it drove through the highways, streets and alleys of Atlanta. By examination of the source ID and the repeater ID stored in the Network Control Terminal, ARNAV personnel could determine how well the surveillance coverage would operate during the Games. This rental car was used throughout the operation as a mobile monitor of all datalink messages.

A set of flight test schedules and checklists (provided by SAIC) was used to guide procedures during the flight test. An orientation flight around the Atlanta area was scheduled for the morning, to be followed by flight tests; however, the test aircraft did not arrive at Dobbins AFB until after 2 P.M., so the orientation flight was scrubbed and the test routes modified to fit the constraints of available flight time. Omissions included approaches and exits from Hartsfield International and coverage tests in the far southwest portion of the Atlanta area; neither of these omissions was felt by the Test Director to be significant.

The flight test was conducted in VFR weather, and consisted of maneuvers at different distance and altitude in an urban environment. Helicopter 140SP departed Dobbins AFB at 3:30 P.M., and flew for 1 hour and 41 minutes. The helicopter was tracked almost continuously on both the ARNAV and Harris display from the time of avionics power-up, with brief outages as noted below.

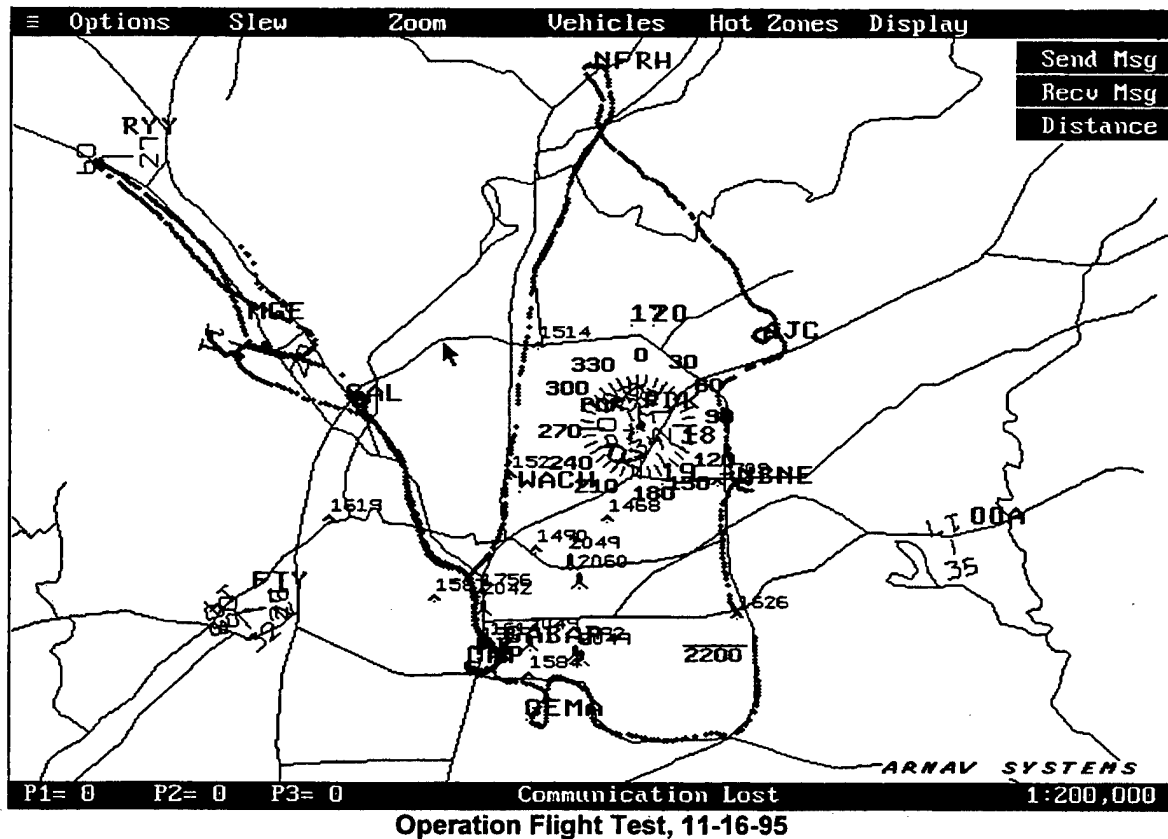
Both "canned" and free-format messages were exchanged between the test aircraft and the ARNAV Network Control Station. Post flight briefing indicated that there was no significant delay observed in transmission of these messages, and that all messages (13 uplink and 16 downlink) were received at both the aircraft and at all ground stations.

An analysis was conducted of the CNS/A transmitted data. The CNS/A was set up to transmit its GPS derived position every 4 seconds. Technicians determined the number of valid hits by taking the total flight time in minutes, divide by 15 (15 reports per minute), and compare this number with the total ADS-B position reports recorded at the ARNAV Network Control Station. The majority of lost position reports represent a gap of only one lost position. 96.14% of the time a position report was received within 8 seconds.

A breakdown of missed position reports revealed that the worst case was a maximum interval between positions reports of 32 seconds during maneuvering on low approach at the Galeria landing site. Anecdotal information supplied by SAIC personnel on the flight indicated that they were not surprised that position reports would be lost due to the low level of flight within close surrounding proximity to buildings and terrain, tight maneuvering at low altitudes, and the antenna placement on the tail boom.

The distribution of interval between position reports was as follows:

# reports greater than 16 seconds = 8	(8 periods of 4 missed positions)	0.63%
# reports greater than 12 seconds = 17	(3 missed positions)	1.34%
# reports greater than 8 seconds = 49	(2 missed positions)	3.86%
# reports greater than 5 seconds = 150	(1 missed position)	11.81%



Surveillance within the current National Airspace System (NAS) currently uses a combination of primary and secondary surveillance radar (SSR). If ADS-B is to be considered as a viable alternative, it will need to offer performance equivalent to, or better than the existing surveillance systems.

A review has been made of the performance provided by the most recent radar-based surveillance systems used within the NAS, as well as the Federal Aviation Administration's current baseline performance requirements for surveillance services in various operational domains. Table 1 is a summary of the NAS Performance requirements.

The performance requirements for a vertical flight, short-haul transportation system have not been defined. To achieve 207 feet accuracy, a Local Area Differential GPS correction would be required.

Parameter	En Route	Terminal	Airport Surface	Approach	remote airspace	Air-Air
Maximum update rate	12.1 secs	5.33 secs	1.0 secs	1.0 secs	12.1 secs	1 sec< 5nm 4sec>14nm
Probability of update	98%	98%	95%-1 sec 99%-2sec	>99%	98%	90%
Message Integrity	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}	10^{-7}
Position Accuracy	616 feet	207 feet	<= 3 meters	9 meters	616 enroute 207 term.	TBD
System Availability	99.999%	99.999%	99.999%	99.9%	99.9%	TBD

Table 1, Summary of NAS Performance Requirements

Message Reliability

The message acknowledgment function of the CNS DataLink structure allows the system to have reliability of message transmission in excess of 99%. In order to determine the number of re-transmissions necessary to meet the >99% reliability goal, a series of tests were performed to serve as a baseline for reliability metrics.

The test consisted of four datalink boxes operating at 149.895 MHz. The CNS Fixed Station (FSTN) was running X8510CB version software and was connected to a VHF antenna on the roof at the test laboratory. A Intel based 486 microprocessor running at 25 MHz was connected to the FSTN to receive the text messages. The CNS Mobile Station(s) (MSTN) were running a test version developed from T8510CA software that automatically generated 500 text messages at a interval of 1 second. The MSTN datalink equipment was reset after the 500 messages had been sent. The MSTN(s) were connected to three different VHF antenna (1/4 wave multi-band unity gain, 1/4 wave magnetic mount unity gain, and a 5/8 wave 3dB gain).

The text messages of 80, 60, 40, 20 bytes in length including header and checksums were generated. Each message had a field where a message count was recorded. The Monitor Station had a terminal connected to the data log port (port E) to determine number of messages received over the RF datalink. The test consisted of 11 different trials, 6 ground based and 5 airborne, at several locations using four different ADLP boxes with one of the 3 antennas. The ground testing did not have a direct line of sight between the antennas of the MSTN and FSTN, which resulted in signal-to-noise levels that are consistent with worst case atmospheric scenarios.

The flight tests were conducted in VFR weather, and consisted of 5 different trials at different distances and altitudes. At each distance the plane would perform a standard rate turn (3 degrees per second to determine antenna shadowing effects) until the 500 messages were transmitted (approx. 9 minutes). Trials were conducted 10 miles, 20 miles, 30 miles, and 50 miles, at altitudes that varied from 3000 to 8000 feet MSL.

Results of Message Transmission Tests

The lost % refers to the percentage of messages that were lost over the RF link in the various antenna and power output configurations. The CS % refers to the percentage of messages received that contained one or more bit errors in the data portion of the text message. The no error % refers to the percentage of messages that were received with no errors on first transmissions.

Test #	Unit and antenna	power	lost %	CS %	no error %
Ground test					
1	Unit 3 - 5/8 antenna	4W	03.4%	08.0%	88.6%
2	Unit 3 with 1/4 mag mount	4W	42.0%	05.0%	53.0%
3	Unit 2 - 5/8 antenna	4W	08.4%	11.6%	80.0%
4	Unit 2 - 5/8 antenna	2W	13.0%	16.2%	70.8%
5	Unit 1 - 5/8 antenna	4W	08.4%	17.0%	74.6%
6	Unit 3 with 1/4 ant.	4W	03.6%	08.4%	88.0%
Flight Test					
7.	10 NM, 3000 feet MSL	4W	02.3%	00.3%	97.4%
8.	20 NM, 3000 feet MSL	4W	03.0%	02.1%	94.9%
9.	30 NM, 5000 feet MSL	4W	02.6%	00.0%	97.4%
10.	40 NM, 8000 feet MSL	4W	06.0%	01.0%	92.9%
11.	50 NM, 8000 feet MSL	4W	03.4%	00.0%	96.6%

The mean probability for the trials using the various antenna and power settings 84.9% chance of getting message through with no errors. The worst results came from 1/4 wave magnetic mount antennas, with minimal grounding plane. Using the empirical test data of the probability that a message being received on the first try, and assuming that the desired message receipt probability is 99.9%, it was determined that the number of transmission retries the originating station will conduct will be 6. The software that generates messages that require acknowledgment will attempt to send the message 6 times until it either receives an acknowledgment from the addressed ADLP box, or the user sends an acknowledgment using a Multi-Function Display or text message station.

Radio Frequency (RF) Network

The CNS ground network is based on a Carrier Sense Multiple Access with Collision Avoidance protocol (CSMA/CA), and must manage a large number of vehicles in a small geographical area. Forty vehicles can update their position reporting within 5 seconds using one frequency. If more vehicles are in a given RF area, the CNS Control software allows for prioritization of user response. Aircraft on approach may use a 5 second reporting scheme, while overflying aircraft report every 30 seconds. By implementing prioritization based on mode of flight, many more vehicles can be tracked.

Each ADLP in the network monitors the radio frequency saturation, and make decisions of interval reporting in order to minimize RF data collisions. The CNS Control Station will monitor the network and override the system operating mode as necessary to conserve bandwidth. If the pilot emergency switch is set, the Network Control Software will automatically enable that vehicle for a 1 second priority response rate. Other prioritization methods may be implemented through the CNS Network Controller software, and includes position, speed, mode of flight, and other user defined factors to establish priority.

Carrier Detect

The basis of determining when a station can transmit is by evaluation of carrier detect (CD). CD is measured by all ADLP stations every millisecond (ms), and includes the carrier produced by other ADLP stations, voice audio, and its own carrier. The time the CD becomes active and the time since the last CD was active is measured, and a ratio of activity to non-activity is determined. This ratio is one factor in setting the response time interval. Other factors that influence the transmit interval are number of stations in a given area, message length, distance between stations, number of fixed ADLP sites in the RF area, and stations that cannot see each others carrier, but can be seen by other stations.

If two or more stations are waiting for CD to become inactive in order to transmit, the stations must be separated by at least 6 ms to ensure the carrier of 1 or more stations in a crowded area will not transmit on top of each other. It takes 5 ms from the time the carrier is present at the receiver plus system latency (worst case is 1 ms) before a station can detect the carrier.

The carrier detect is evaluated every second on a 15 second interval moving average. A record is kept of the maximum and minimum 1 second carrier saturation windows during each 15 second interval. Every 15 cycles the sum of each of the individual 1 second CD samples is determined. Decisions about changing the current transmit interval are made based upon the 15 second CD saturation level. The maximum and minimum window measurements allow a station to be able to move from a heavily used transmit interval to one less heavily used. This movement is computed by the microprocessor in a random manner so that all stations in the window will not move to a new window. The move is implemented by increasing or decreasing the stations transmit interval by one second per transmit interval time.

In order to prevent two stations that can not hear each other from transmitting within the same time, the interval is made to be unique to each transmitting station. The 24 bit station ID number is used in

calculating the interval to insure that the interval is likely to be unique. In the adaptive broadcast mode, the station continually adjusts its actual transmit interval until it reaches the calculated target interval. If the target interval is greater than the current interval, the station will automatically jump to the new interval. If the target is less than the current interval, the station approaches the target interval by small jumps per CD evaluation cycle, and is repeated until the target interval is reached. The target interval is changed to the pre-defined intervals when the saturation reaches specific extremes.

The transmit cycle is made of three separate parts;

1. transmit wait interval
2. transmitter key up and synchronization time
3. transmit and data dribble time

The transmit wait interval begins when the carrier is dropped and includes transmit to receive turn around time. If the transmit wait interval has already expired at the time the transmit interval expires, the station will transmit immediately. If the transmit wait interval has not expired, the station will wait for the time remaining in the transmit wait interval before transmitting. If carrier is detected during this period, the transmit wait interval will reset.

The transmit wait interval must be different from all other stations by at least 6 ms. This 6 ms difference is for the case when many vehicles are in an area and the majority of vehicles can hear each other.

The transmitter key up and synchronization time is approximately 30 ms. The transmit time is based upon message length, at 1.04 milliseconds per byte of transmitted data.

Radio waves travel at approximately 300 million meters per second. At 50 nautical miles, the transmit propagation delay is approximately 270 microseconds. After a station stops transmitting, it will take approximately 5 ms + processor latencies for any station listening to determine that the carrier has been dropped. Transmitting propagation delays are not significant in the ABDS architecture.

Radio Frequency Network Capacity

The CNS Radio Frequency Network capacity may be analyzed based upon assumptions of required reporting times, number of messages transmitted, and the number of Mobile nodes that must be serviced. Typical timing of message services is as follows:

Message type	bytes	Tx time including guard time and acknowledgment
Position report	42	50 ms (milliseconds)
Text Message	56	64 ms transmit, 20ms acknowledgment - total of 84 ms
Weather Graphics	51	58 ms
Text Graphics	60	63 ms
RTCM 104 Diff.Corr.	100	104 ms

The preponderance of message traffic is in position reporting from mobile vehicles. Typical scenarios for a terminal operation would include 10 vehicles giving position reports every 5 seconds, 75 vehicles giving position reports every 15 seconds, 75 vehicles giving position reports every 30 seconds, 50 vehicles giving position reports every 60 seconds, text messages on local service volume of 4 per minute, broadcast graphic message data, text weather messages, and RTCM Differential Correction messages every 30 seconds.

Tx type	report interval	bytes per minute	overhead in bytes	Tx per minute
10 position reports	5 seconds	5,040	504	
75 position reports	15 seconds	3,024	1,260	
75 position reports	30 seconds	1,512	630	
50 position reports	60 seconds	756	210	
10 time reports	15 seconds	224	52	
graphic weather	3 seconds	0	0	
text weather	3 seconds	0	0	
RTCM Diff Cor	30 seconds	200	0	
Total		30,040	2,656	60%

Typical RF Network loading

The available bytes per minute using the CNS ground architecture at 9600 baud is 55,380. The network transmission loading as shown in the above table is 32705/55380, or 59%, excluding radio transmission overhead. Overhead consists of Transmission wait period of 6ms and Pre-key time of 30ms. Repeaters on the RF Network reduce pre-key time due to fact that all messages repeated within the last time interval will use only one pre-key time.

To analyze the capacity, the ratio of bytes used per minute to the available bytes per minute for one frequency is expressed as the percentage use of the available frequency. When the capacity exceeds 1.0, either an additional transmit frequency is required or prioritization of reporting intervals must change.

Messages Transmitted during flight test were as follows:

Note: time is in UCT (Universal Coordinated Time)

date	time	
111695194640		DATALINK TEST TWO
111695195847		ARE YOU NOW IN CITY CENTER?
111695203938		N140SP CITY CENTER
111695083948		THE LANDING AT GEMA COMPLETE?
111695204219		N140SP PROCEEDING TO NBNE
111695084240		MESSAGE TO FOLLOW
111695204815		TO MAKE 4:30 DEADLINE DELETE ROUTE 8,910 - MAKE ROUTE 7 I-20 285
111695205015		TO GALERIA AND CONTINUE AS PLANNED -
111695205048		GIVE LANDING NOTIFICATION OF LANDING AT BANK - DID YOU RECEIVE PREV. MESSAGE?
111695205312		DOWN ON NBNE
111695085336		N140SP DEPARTING TO AJC
111695085428		FUEL 44:30 REMAINING SAYS THE CAPTAIN
111695085519		DID YOU RECEIVE ROUTE CHANGE?
111695205647		AFFIRM, CHUCK TOLD CAPTAIN OF INTENSIONS PRIOR TO YOUR MSG
111695085829		DEPARTED AJC AT 3:57:30
111695085920		PROCEEDING TO ROSWELL VIA JIMMY CARTER
111695090103		GOING TO QUESTION #12
111695090159		PROCEED - WE HAVE YOU ON ADS
111695210320		ROGER
111695090404		APPROACHING NFCH, NO. FULTON HOSP.
111695090520		PAST OVER-GA400
111695090558		ARE YOU GOING TO GET GALERIA NOISE TEST?
111695211042		AFFIRM, GALLERIA WILL GET NOISY!!
111695091259		FRANK, I HAD AN "OUT OF STACK SPACE ERROERROR, BUT, O.K. NOW
111695091359		OVER TOLL PLAZA, ANYONE HAVE FIFTY CENTS
111695091455		ETA TO GBH 2 MINUTES
111695091812		ALL STATIONS HAVE BEEN NOTIFIED OF INTENTIONS
111695211936		EXECUTING STEEP APPROACH TO GBH
111695091952		GOING TO ROOFTOP, DUE TO HELICOPTER ON PAD
111695092028		TO NATIONS BANK MITCHELL ST. RIGHT NOW!!
111695092125		GIVE FUEL STATUS ABEAM CEMETERY
111695212404		OFF MITCHELL ST, TO GALLERIA MALL DIRECT
111695092405		CLEARED DIRECT GALERIA
111695212456		ROGER, TIME FOR NOISE MANEUVERS STILL AVAIL. TIME REMAIN 16:30
111695092550		CHUCK WILL MEET OUR GUYS AT THE COMPLETION OF MISSION
111695212750		GALLERIA 2 MILES
111695093007		MESSAGE RECEIVED - UNDERSTAND 1 MINUTE OUT FROM GALERIA -
111695213102		SECOND PASS COMPLETE, GOING TO APPROACH TO LANDING
111695093335		PRETTY BAD TRACTOR TRAILER WRECK ON I75!
111695093514		DOWN AT GALERIA
111695093542		IS THAT WRECK ON NORTHBOUND OR SOUTHBOUND I-75
111695213611		OFF GALERIA RETURN TO DOBBINS
111695093604		DOES CHUCK HAVE THE RADIO?
111695093820		YES - CHUCK HAS THE RADIO
111695213908		THANK YOU
111695093956		GREAT TEST
111695214019		THE DINNER IS ON DOUG
111695214036		DOWN ON GROUND

CNS/A Airborne Equipment

Navigation Display

The Multi Function Display (MFD) aboard the aircraft has a standard display of moving map that relates the aircraft position to the world. This moving map has pilot selectable scaling between 3 and 150 nautical mile.

Cockpit Display of Traffic Information - CDTI

Cockpit Display of Traffic Information (CDTI) is an airborne system used for detecting and displaying properly equipped aircraft near other properly equipped aircraft. CDTI includes an ADLP with integral GPS receiver, a MFD (Multi Function Display and control unit), and an antenna. The CDTI system works as follows:

- The GPS receiver determines the target aircraft position and its altitude within the accuracy of non-differential GPS (including the Selective Availability (SA) feature, which may degrade accuracy up to 100 meters).
- The GPS position and altitude is transmitted by the target aircraft to all other aircraft within line of sight up to a range of approximately 150 NM.
- This signal is received by other properly equipped aircraft. The processor in the ABDS compares the position and altitude of the target aircraft (up to eight targets at one time) to its position and altitude (determined by its ABDS), calculates a bearing and relative altitude, determines the proper type of traffic icon (based on the degree of threat).
- The proper icon is displayed on the MFD in the proper bearing, range, and relative altitude to your aircraft. Range on the display is selectable, from 3 to 19 NM from your aircraft.

Note: CDTI is unable to detect or display any aircraft that is not equipped with an ABDS system.

CDTI is selected and controlled through line select buttons on the MFD. The CDTI display shows the position of target aircraft and identifies the relative threat of each target aircraft by using different icons. A climb/descent arrow appears immediately to the right of the icon if the target aircraft is climbing or descending more than 500 feet per minute (fpm).

Conventional ATC procedures, including the "see and avoid" concept, continue to be the means of separation and traffic avoidance. CDTI provides assistance in rapidly visually acquiring other aircraft for visual separation and "see and avoid" maneuvers.

CDTI monitors the airspace surrounding your aircraft by detecting position transmissions from CNS/A equipped aircraft. This position information, and the position information for your aircraft, is combined to determine bearing, range (with range rings from 3 to 19 NM), and relative altitude between your aircraft and up to 8 other aircraft, and whether the targets are climbing or descending. CDTI display is based solely on these factors. Any aircraft within certain ranges and relative altitudes will be displayed, with different icons representing the degree of threat based on these ranges and altitudes.

The accuracy of this system is approximately 30 degrees horizontally and vertically from the actual position of the target aircraft. This is an angle that should enable you to visually acquire the target by looking in the 30 degree cone around the location indicated on the display.

Surveillance volumes is the volume of airspace within which other aircraft are displayed on the CDTI display. Although CDTI can receive position information for up to 150 NM, the range volume is limited to 13 NM on the display. The range volume is an ellipse, with about 80% of the volume forward of your aircraft. The CDTI function can receive position information for any altitude, the altitude volume is limited to $\pm 3,000$ feet or your aircraft on the display. Aircraft beyond this relative altitude are not considered a threat within the maximum range volume.

CDTI Traffic Display Icons

CDTI will display three different traffic icons, based on the target aircraft's range and relative altitude. Relative bearing and range to the target aircraft are shown by the position of the target aircraft icon in relation to your aircraft icon, located in the lower center of the display. The icons change shape and color as the distance between your aircraft and a target aircraft decreases, to represent increasing levels of threat.

The target aircraft icons may also have a relative altitude tag, showing the relative altitude of the target aircraft from your aircraft in hundreds of feet. A + sign means the target is above your altitude, and a - sign means the target is below your aircraft. A "00" means the target aircraft is at your altitude. For example, "+10" means the target aircraft is 1,000 feet above your aircraft (± 30 degrees); "-04" means the target aircraft is 400 feet below your aircraft (± 30 degrees). An arrow immediately to the right of the target aircraft icon will show if the target is climbing or descending more than 500 feet per minute.

There are three levels of threats displayed on the CDTI, Traffic Detected, Proximate Advisory, and Traffic Advisory. Definitions of these levels of threat are:

Traffic Detected - An open white diamond indicates that a target aircraft is less than 12.5 NM, but more than 6 NM, from your aircraft, and less than $\pm 3,000$ feet relative altitude, but greater than 1,200 feet relative altitude to your aircraft.

Proximate Advisory (PA) - A filled (white if in color) diamond indicates that a target is less than 6 NM, but more than 2.5 NM, from your aircraft, and less than $\pm 1,200$ feet relative altitude to your aircraft.

Traffic Advisory (TA) - A filled (amber if in color) circle indicates that a target is less than 2.5 NM from your aircraft and less than $\pm 1,200$ feet relative altitude to your aircraft.

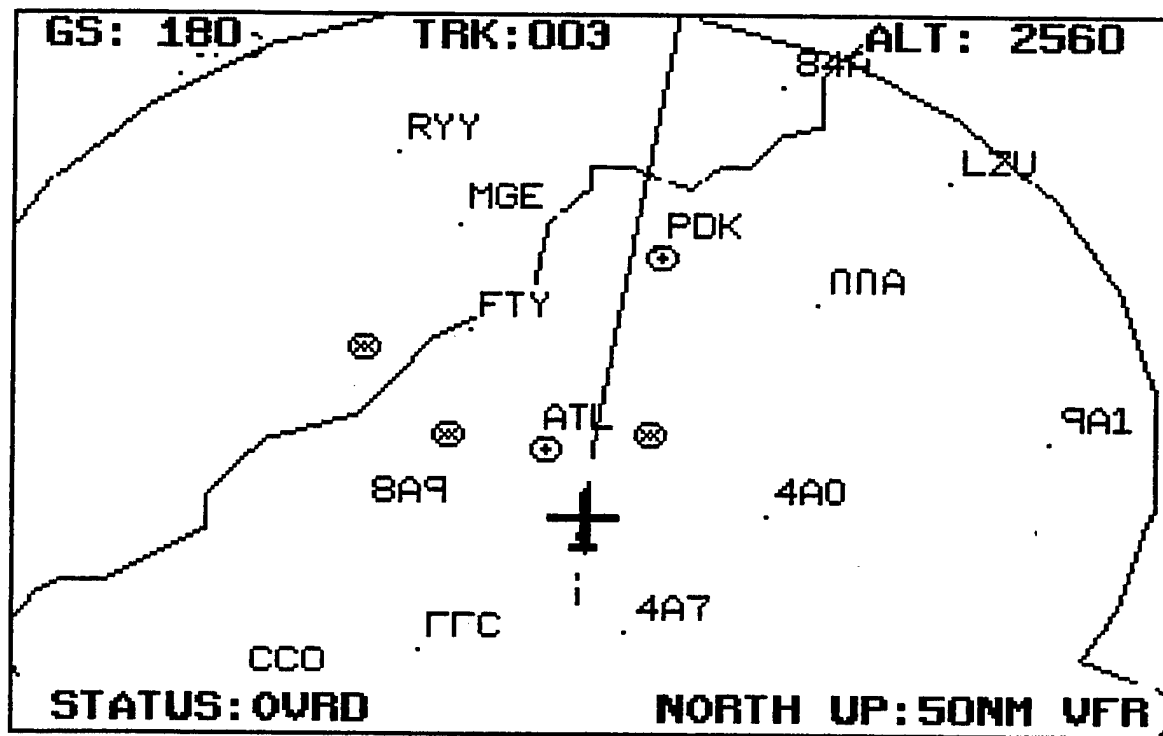
IMPORTANT: The pilot must not initiate any evasive maneuvers based solely on the CDTI display information. Use the CDTI display as an aid to quickly visually acquire the target aircraft, and base any evasive maneuver solely on the bearing, range, relative altitude and climb or descent you detect visually for the target.

CDTI Controls and Displays

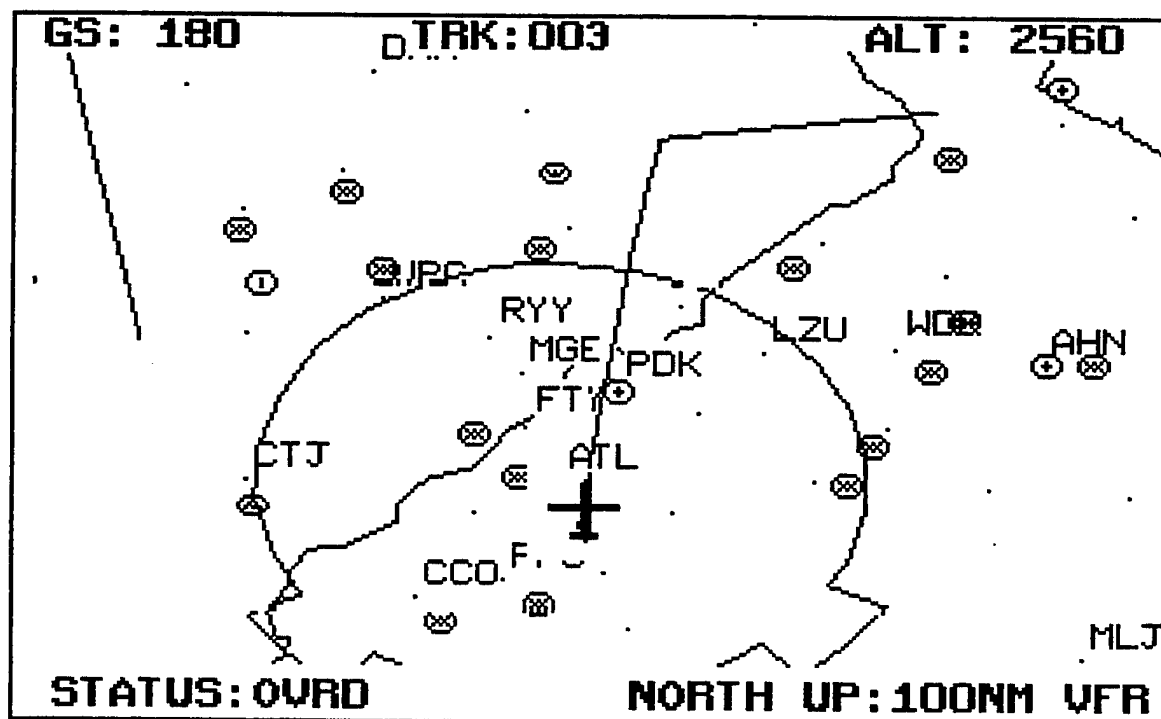
The CDTI functions, selection on/off and range rings, is controlled by the line select switches on the MFD. CDTI may be toggled on by first selecting the data link menu, by pressing any line select button, and then pressing the "CDTI" button on the lower left part of the menu list. CDTI may be toggled off by pressing the "DL" data link button on the lower left of the CDTI display, and then pressing the "CDTI" button on the lower left part of the menu list.

The range may be incremented when in the CDTI mode, by pressing the "RNG+" or "RNG-" buttons on the upper left corner of the CDTI display.

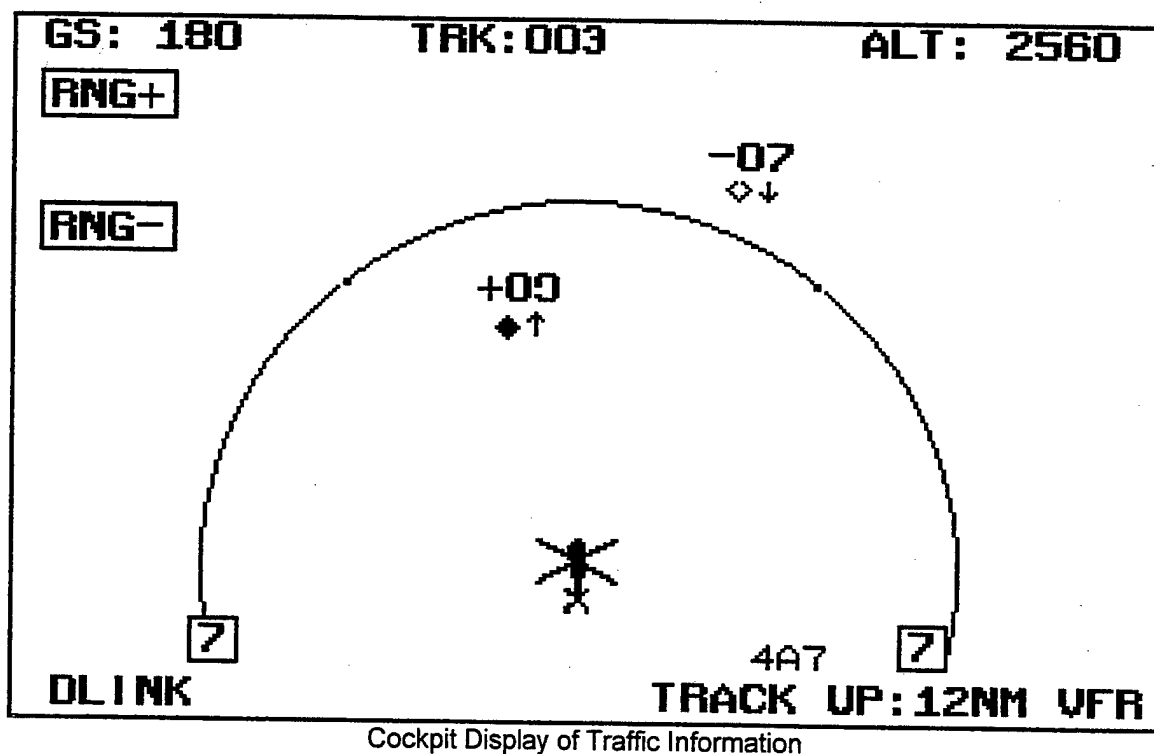
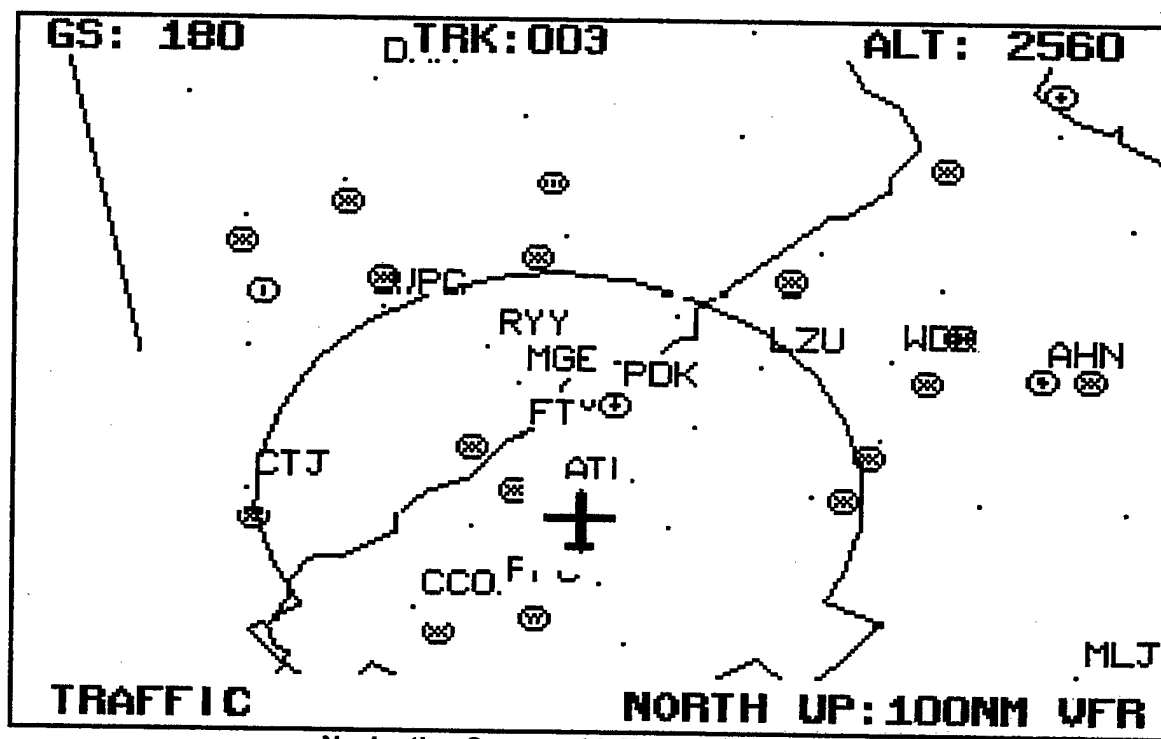
Traffic Displays

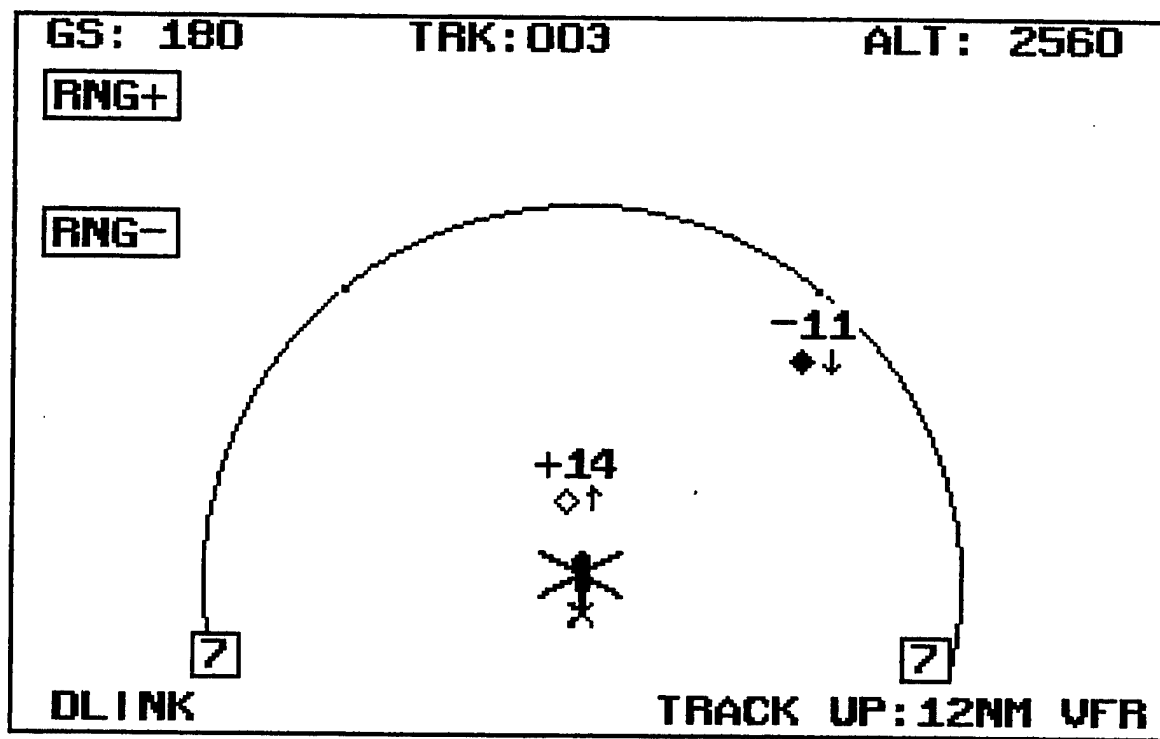


Navigation Screen with Status Monitoring



Navigation with Graphical Flightplan via DataLink





Cockpit Display of Traffic Information

The CDTI display shows the bearing and distance to any target aircraft relative to the “your aircraft” symbol, which is located about 20% up from the bottom center of the display. The CDTI display is always “track up”, with your aircraft’s flight path directly up on the display.

The display range is found in the boxes attached to the ends of the range ring, and read in nautical miles. This range is the distance from the front and both sides of your aircraft. The total display distance is listed on the lower right of the display.

The bottom of the display indicated “track up”, which is the format of the moving map on which the CDTI is displayed. The display also depicts, and overlays, moving map symbols (airports, obstructions); only this limited moving map symbology is presented when in the CDTI mode.

Weather and Traffic Displays

The same display may provide weather information. This information is displayed in the north-up orientation. Further information may be found in the WeatherLink section of this document.

When traffic is detected, the weather display will indicate “traffic” at the 8 o’clock position on the display. CDTI may be selected by pressing the line select button opposite the “traffic” indication. When CDTI is selected, the orientation will automatically become “track up” and the scale will be 5 nautical miles.

CDTI Operating Procedures

CDTI may be turned on at any time. On the ground, it will provide the position of any properly equipped aircraft. CDTI warns the pilot with a “traffic” indication when in the weather or moving map modes, and by depicting an icon when in the CDTI mode. The pilot should not initiate maneuvers based solely on the CDTI display, but should use CDTI to visually acquire the target, and then maneuver based on the targets position and direction determined visually. The CDTI lacks the resolution necessary to make evasive maneuvers based solely on the CDTI display.

Any time a Traffic Advisory (TA) is depicted on the display, immediately conduct a visual search in a cone 30 degrees horizontally and vertically around the position of the traffic as indicated on the CDTI display. If the target is acquired visually, maintain visual contact to ensure safe separation.

The CDTI will only display aircraft equipped with ABDS equipment that is operating normally. CDTI is unable to detect or display any other aircraft. Only 8 target aircraft can be displayed at one time. Only aircraft within 12.5 NM and +/- 3,000 feet relative altitude are displayed. Accuracy in position (bearing, range and altitude) of both target and your aircraft are limited by GPS accuracy, which may be in error by as much as 100 meters.

WEATHER DATALINK

Weather is, and will continue to be, a critical factor in aircraft operations. It is the single largest contributor to delays and a major factor in aircraft accidents and incidents. In 1990, twenty-seven percent (27%) of general aviation and thirty-three percent (33%) of air carrier accidents were weather related. Forty-one percent (41%) of the delay time was weather related, with an associated delay cost of \$1.7 Billion. The National Aviation Weather Program Plan (NAWPP) was published to document the aviation user's needs, and lend sound organization research and development to accomplish the solutions to those needs.

A study by Ohio State University reports that a principle difficulty pilots experience in making good flight decisions is the timeliness and availability of weather data. Word of mouth reporting transmitted over congested radio channels is inefficient and sometimes impossible when critical weather is present and a great number of pilots are working the radio. **Obtaining current and accurate weather information is vital for safe flight operations.**

General Aviation (General Aviation) aircraft using the NAS every day represent approximately 75% of all flight operations and 37% of all IFR operations. The current pilot reports (PIREPS) system does not always provide accurate and significant information because the pilot workload in adverse weather prevents taking time to make a PIREP when they are most needed by other aircraft. With an Electronic Pilot Reporting (EPIREP) system, airplanes transmit automatically measured temperature, pressure, relative humidity, altitude, turbulence, icing, latitude and longitude at regular intervals. This data will provide greatly improved real time three dimensional weather awareness with a resultant major impact on flight safety. The same collected data can provide thousands of weather sensors reports to the NWS for ultimate dissemination to all airplanes. With increased weather awareness, more efficient use of the off airway airspace in the NAS can occur. This in turn results in reduced traffic congestion, allow General Aviation aircraft to use direct routings safely, and to improve airport capacity.

The weather research organizations are well on their way to smart algorithms for enhanced weather modeling, but lack sufficient REAL DATA to yield valid nowcasts that are of immediate value to the pilot who is threatened by the local mesoscale conditions. Stated simply, the NWS does not have enough real time, airframe-collected, mesoscale physical data in the lower altitudes to support accurate weather modeling. The scheduled airlines have *limited* capability of data acquisition at steady state altitudes between 29,000 feet and 41,000 feet – precisely where the most threatening weather systems to General Aviation aircraft do not occur!

Most safety threatening and dangerous convective activity is between the surface and 18,000 feet. Ironically, this is where the lesser capable aircraft pilots conduct most of America's daily flying operations. At any given time, there are thousands of General Aviation aircraft airborne. This fleet of aircraft could provide a vast network of airborne weather sensors for the collection and dissemination of accurate real-time three dimensional weather information to other aircraft, Air Traffic Control Centers, Flight Service Stations, TRACON, and weather forecasting facilities. One could think of this concept as AAWOS, or Airborne Automatic Weather Observation System, to supplement the ground based AWOS network. This

network of airborne reporting sites will greatly improve weather prediction for all users of weather products.

The National Airspace System (NAS) is utilized by a wide range of users with different operating needs. Users range from air carriers engaged in domestic and international air transport, to air taxis and commuters, to military pilots flying missions for National Defense, to General Aviation pilots. These operations involve all phases of flight: Departure/climb-out, en-route, oceanic, and approach to landing. As we move to the future with ever increasing demand on the National Airspace System, there is an even greater need to increase system capacity, reduce delays, improve flight efficiency, reduce Air Traffic Controllers workload, and increase safety.

Current NWS Data Collection Services

The National Weather Service (NWS), along with the National Oceanic and Atmospheric Administration (NOAA), are the primary agencies responsible for collection of weather data in four general categories;

- surface observations
- upper air observations
- weather radar
- weather satellite

Surface and upper air observations:

The NWS operates a wide variety of stations and observation systems to provide weather products. Surface weather conditions are observed and reported at over 1,000 land stations nationwide. Upper air data is generally obtained from rawinsonde balloon soundings taken at 94 NWS locations twice per day. Additional data on upper air observations are collected via Pilot Reporting from pilots operating within the NAS. These PIREPs may provide information on winds and temperatures aloft, and usually are the only source of information on aviation hazards such as turbulence and icing. However, PIREP's are reported infrequently and are prone to reporting errors, pilot workload limitations, and pilot subjectivity of the encountered phenomena.

Weather Radar

Conventional weather radar observations are taken at 128 National Weather Service locations. Fifty-six of these are network radar sites operated on a continuous basis. The remainder are local warning radar's operated as needed to detect potentially severe weather. Radar coverage in the western United States is principally obtained by extracting weather information from the air traffic control (ATC) radar's operated by the Federal Aviation Administration.

Satellite systems

Non-military weather satellite systems are operated by the National Environmental Satellite, Data, and Information Services (NESDIS). The satellites currently provide visible and infrared (IR) images of weather conditions over a major portion of the Western Hemisphere, updated every 30 minutes. Polar satellites provide capability to monitor volcanic ash plumes and weather coverage at high latitudes. In addition, NESDIS also receives and redistributes data from the European and Japanese geosynchronous weather satellites.

NWS Planned Improvements

The National Weather Service and the Federal Aviation Administration have embarked on a \$4 Billion capitalization program to enhance weather sensors and processors designed to improve national weather services. The National Aviation Weather Program Plan outlines the overall implementation plan for the next 15 years. Considerable progress is expected for collection and dissemination of weather products as new systems come on-line. These systems include:

- Automated Weather Observing System (AWOS)
- Automated Surface Observation System (ASOS)
- Next Generation Weather Radar (NEXRAD)
- Terminal Doppler Weather Radar (TDWR)
- Geostationary Observational Environmental Satellite (GEOS next)
- Polar Orbiting Environmental Satellite (POES next)

AWOS/ASOS Data Acquisition System (ADAS) will include 537 systems with options for 228 additional stations. ADAS will function primarily as a message concentrator collecting messages from AWOS and ASOS equipment located at controlled and non-controlled airports. ADAS has the ability to distribute *up-to-the-minute* weather data, so pilots have the data they need in a timely fashion.

NEXRAD will add significant data collection capability with its Doppler products of reflectivity, wind velocity, and rainfall accumulation. TDWR will add similar capability in the airport areas.

GOES I-M series will add vertical atmospheric sounding (temperature and moisture) and improved multi-spectral imaging to the current capability. POES next will do the same for the critical polar areas.

Opportunities for Weather Improvements

The National Aviation Weather Program Plan offered no new technology updates for the rawinsonde system (within-the-upper-air) environment. However, the Plan made two significant statements relative to this data collection capacity:

First, "...Even when the (Weather Profiler Demonstration Network) WPDN becomes fully operational, wind profilers cannot replace the rawinsonde stations because they currently do not have the capability to measure the required profiles of temperature and moisture." (Appendix E, page E-16)

Second, "... **PIREPS** have always made a contribution to the aviation observational database.....in data sparse areas.....between normal observation times..... are frequently the **only source of hazard observations** such as icing and turbulence.....In the future, automated reports from the aircraft equipped with **inertial navigation systems** will become a major source of PIREPs. These aircraft will **automatically provide observations** of climb, descent, and flight level winds and temperatures to the ground via systems such as **datalink** or Aeronautical Radio Incorporated Communications Addressing and Reporting System (ACARS). These automated winds will provide **a large data set** to the NMC for analysis and assimilation into the **numerically produced grid winds** and temperatures aloft forecasts." (Appendix E, page E-17)

There is one other aspect of PIREPs that the aviation support personnel who receive these reports are faced with, a built-in technical dilemma. They must decide if the PIREP is **subjectively accurate**. It varies with the type of aircraft (wing loading, de-ice systems, etc.) and pilot competency (experience, weather knowledge, and currency).

Weather System Definitions:

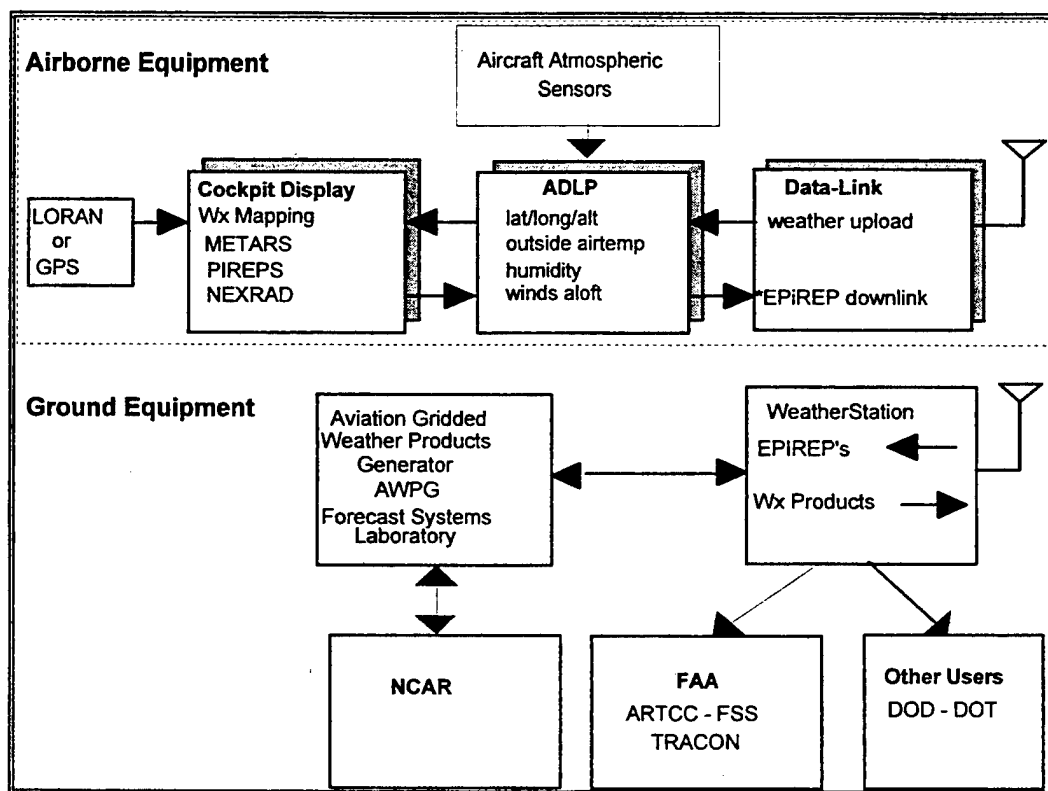
WxStation: - Commercial datalink ground station equipment used for communication with aircraft. The ground stations used for the 1996 Olympics effort used a 9600 baud Radio Frequency modem, transmitting on VHF frequencies using Frequency Modulation (FM) techniques to minimize manmade and atmospheric noise interference. Each WxStation transmits weather data (Hourly Surface Observations, including AWOS and ASOS data) for a radius of 150 nautical miles of its location, and graphical NEXRAD radar images.

Station Repetition Interval (SRI): The SRI is a number between 1 and 9, and represents the time slot of transmission of weather data, repeated every 10 minutes. If the SRI of a WxStation is 4, it will transmit at

4, 14, 24, 34, 44, and 54 minutes after the hour. There is a minimum of 300 mile distance between WxStations with duplicate SRI's to prevent airborne collision of data. Line-of-site distance between aircraft and the ground at 3000 feet AGL is 67 nautical miles. The typical distance between WxStations is 75-125 nautical miles, so at 3000 feet AGL, aircraft will be within line-of-site distance with at least 1 or 2 stations. At worst case, an aircraft will receive weather data updates and issue EPIREPs every 10 minutes. At best case, an aircraft at 10,000 feet AGL will receive updates and issue EPIREPs 7 times every 10 minutes. In some cases, atmospheric attenuation of signal may reduce the number of stations within aircraft line-of-site distance.

WeatherLink

WeatherLink is a system that uses two way datalink to uplink weather products for display in the aircraft, and down-links electronic pilot reports (EPIREPs) of weather conditions aloft from the aircraft. These EPIREPs are collected at ground stations around the country, and forwarded to a central weather concentrator facility.

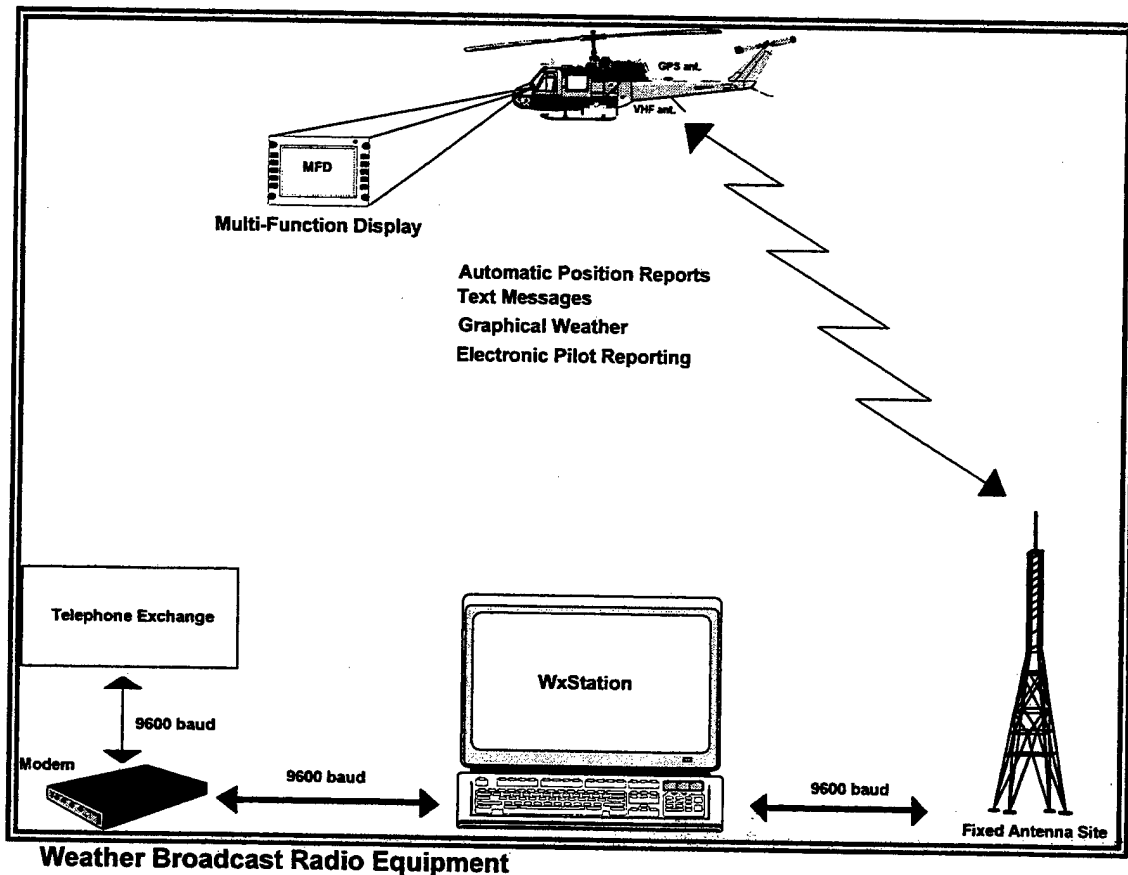


WeatherLink System Block Diagram

The current system of accepting and transmitting pilot reports (PIREPS) leave much to be desired. Accurate and significant PIREPS often are not submitted when they are most needed by other aircraft because the pilot is coping with the adverse weather and is too busy to take the time necessary to make a PIREP. In addition, good weather conditions are often not reported, leaving other pilots unaware of areas of improving weather, further contributing to the \$1.7 Billion in aviation related delay costs. The airborne datalink equipment automates the collection of weather data, and sends the collected data through the down-link portion of WeatherLink.

Broadcast Weather

Broadcast Weather is the up-link portion of WeatherLink. Broadcast Weather gives the aircraft access to the advanced ground based weather data, (AWOS, NEXRAD), so that weather products can be displayed in the cockpit, for use in making critical flight decisions.



Broadcast WeatherLink VHF

Advantages:

- Weather broadcast can serve any number of airborne users, utilizing the spectrum most efficiently
- WeatherLink ground based infrastructure can quickly be expanded at relatively low costs.
- Broadcast Weather airborne datalink equipment designed for lowest cost.
- Broadcast Weather provides valuable operational data exchange capability to all aircraft (air-to-air), to include weather aloft information.
- Broadcast Weather airborne equipment is identical to ground based repeaters, allowing lower manufacturing costs, as well as less complicated spares program
- Minimum Operational Performance Standards (MOPS) for Weather transmission services have been defined by RTCA SC-169 working group 3, and will be presented for approval in 1997
- Broadcast Weather uses advanced Commercial-Off-the-Shelf (COTS) technology based on telecommunication industry explosion of services.

- Broadcast Weather is designed to be fully ATN compliant, following 7 layer OSI protocol. The network design is upwardly compatible with VDL concepts defined in DO-225, and supported by the Federal Aviation Administration Spectrum Office.
- Broadcast Weather has built-in two-way free-form text messaging.
- Analog and digital input allows for atmospheric data to be collected and downlinked in real time.

Disadvantages:

- National Ground Infrastructure not yet aligned with NWS Weather Forecast Offices for fusion of weather data.
- No nationwide frequency allocated within the Federal Aviation Administration spectrum (108-137.995 MHz)

Broadcast Weather Message Structure - Ground to Air

Frame Description

All messages broadcast from WxStations use a common frame format. This frame is made up of three parts; the header record, the data record, and the checksum fields.

Header 13 bytes	DATA 0-245 bytes	Checksum 1 byte
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Header Format

The header contains 8 fields totaling 13 bytes. The two byte synchronization field (FFH, 81H) bytes provide a means to distinguish between the beginning and ending of the transmit sequence. The data length field in the header is used to delimit valid data. The receiver portion of the radio modem must wait between 3 and 5 milliseconds to determine when a transmitting radio has stopped transmitting. The data length field indicates the length of the data, and tells the I/O processor how to parse up the incoming radio frequency data. If the data length field is zero, the data and checksum fields are not present in the message frame.

The message type field is one byte in length. The source identification address (SID) and datalink identification address (QID) are each 3 bytes (24 bits) in length which provides a total of 16,777,216 unique addresses. The time stamp is an 8 bit counter that is incremented with each message frame to aid in identifying duplicate messages. The header checksum is the two's complement addition of the first twelve bytes of the header.

Header Record

<sync><dlen><type><sid><qid><stamp><route><hcksum>

<sync>	2	0xFF, 0x81
<dlen>	1	# data bytes
<type>	1	0x01 mobile/fixed CNS-A position, analog data, and bit status
		0x02 Initial GPS position/date/time
		0x03 RTCM 104 Differential correction data
		0x04 text message
		0x08 8 kilometer base reflectivity NEXRAD mosaic with lightning Wx broadcast
		0x09 4 kilometer base reflectivity NEXRAD mosaic with lightning Wx broadcast
		0x10 Network Control
		0x11 Load Encryption Key
		0x41 Sequence Reports (SA)
		0x42 AIRMETS

0x43 SIGMET
 0x44 Formatted SA
 0x45 Formatted SA Extended
 0x46 Lightning Strikes - Convective Activity
 0x80 Status Message

<sid>	3	24 bit ID	0 - 16,777,216	originator of message
<qid>	3	24 bit ID	0 - 16,777,216	last CNS-A to repeat message
<stamp>	1	time stamp	8 bit unsigned number incremented by sender per message sent	
<route>	1	7	fixed repeat	0 = message not repeated by fixed site 1 = message has been repeated by fixed site
		6	alias	0 = no alias 1 = 6 character alias in data portion
		5	destination	0 = no destination 1 = destination ID contained in first three bytes of data
		4	ack message	0 = normal message
		3-2	ack bits	00 = no ack 01 = ack from destination 10 = ack from first fixed CNS-A site to hear 11 = ack from all CNS-A stations
		4	ack message	1 = ack of previous message - identified by time stamp
		3-2	ack bits	00 = roger 01 = wilco 10 = unable 11 = message not received - please retransmit
		1	repeat	0 = repeat 1 = do not repeat
		0	direction	0 = inbound 1 = outbound
<chksum>	1	sum of previous 12 bytes, invert lower 8 bits, add 1		

Weather Data Message - 8 kilometer NEXRAD base reflectivity

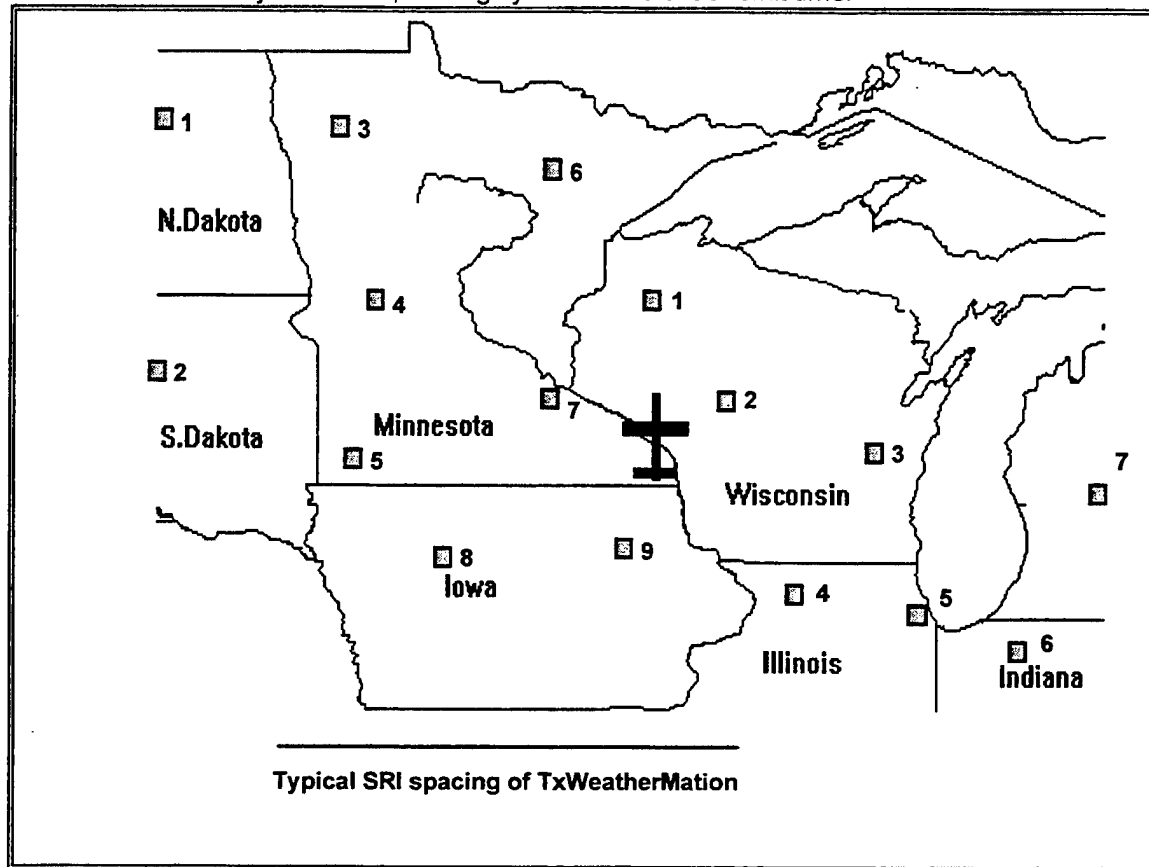
<header><chksum><data><chksum>

Weather data is always formatted for broadcast mode, so all airborne receivers will receive graphical weather data. These messages are variable in length and are displayed on graphical workstations. Message terminals with no graphics display will ignore this message. Aircraft equipped with graphic display terminals will display moving map depiction with graphical weather overlay.

<data>	2-35	1 row of 8 kilometer square grids that represent graphical weather data. The data is run length encoded, with a maximum length of 35 bytes.	
	1	location zone of 5 degree X 5 degree (latitude & longitude) coverage area	
	1	sequence number - row number (1-69)	
		bits 0-7 row number (1-69)	
		bit 7	graphical Wx type indicator 0 = NEXRAD Mosaic base reflectivity 1 = Satellite image
<chksum>	1	data checksum	

Each data record represents sixty-nine (69) 8 kilometer (5 statute mile) grids within a 5 degree longitude by 5 degree latitude area. Due to the polar convergence of longitude line, as latitude increases or decreases from the equator, fewer grids are needed to span the 5 degree longitude lines.

Each grid is encoded into a 2 bit sequence that allows for 4 color levels for any graphical weather product. These 2 bits are combined into a 35 byte sequence encoding the maximum of 69 8 kilometer wide columns. A future version of the broadcast message structure will allow Run Length Encoding to reduce the size of the transmitted weather file. Run Length Encoding (RLE) is an algorithm that analyzes data for repeating patterns, and encodes the data into a length - pattern sequence. Due to the recurring nature of weather, RLE offers an excellent loss-less compression routine. Typical compression of weather phenomena will be greater than 50%, so an area of up to 122,000 square miles of weather data would result in less than 2000 bytes of data, or roughly 2 seconds of transmit time.



An aircraft flying at high altitudes may receive multiple Transmit Wx Station transmissions per 10 minute period, but since different SRI's have been assigned, no data collision will occur. The pilot may choose to ignore transmissions that are not relevant to the flight path of the aircraft.

The Broadcast Weather system will greatly enhance safety in the cockpit, and decrease costly delays due to non-timely weather reporting. Pilots who do not have the onboard equipment will also receive great benefit through Flight Service Stations (FSS) or ATC's enhanced weather awareness.

Broadcast Weather provides a symbiotic relationship between air carrier operations and general aviation aircraft because each provide different elements to the weather picture. Airlines operate in the lower atmosphere only around population centers (hub and spoke system) while general aviation fills in the gaps of weather knowledge left vacant by hub and spoke airline routings.

Weather Data Block to be transmitted

WxStation Station ID, latitude, longitude, time, SRI number

All Sequence reports within a 150 nautical mile radius of the station

Pilot reports (including electronic pilot reports) within 150 nautical miles of station

AIRMETS and SIGMETs that affect area within 150 nautical miles of station

WxStation Health Status Indicator of all stations within 500 mile radius

Checksum for error detection

Typical data transmission block sizes are:

Description	Bytes
WxStation ID, latitude, longitude, time, SRI	20
20 Sequence reports (average of 60 bytes each)	1200
10 Pilot reports (average of 60 bytes each)	600
AIRMETS, SIGMETs	400
NEXRAD Radar image 400 by 300 NM	2900
NEXRAD Radar image - National 64 km grid	2900
Health Status (20 at 5 bytes each)	100
Checksum, framing bytes	4
Total message length	8124 uncompressed
Transmission time	Approx. 4-5 seconds with compression

EPIREP / Position Report - Air to Ground

Position report / EPIREP data

This message type is made up of 8 fields and is 29 bytes long. There are eight discrete input bits that are packed into the discrete input byte where input 0 is bit 0, input 1 is bit 1, etc. These input bits determine how the CNS-A is configured; mobile / fixed, whether messages are repeated, RF modem power (4W or 2W), and a user selectable switch entry. There are eight channels of 10 bit Analog to Digital Conversion (ADC) values that are extended to 12 bits and then packed into a 12 byte field. This extension to 12 bits is to allow for future growth to 12 bit resolution on the ADC. The status flag contains the most significant bit of the time of day field and 4 status indications of the CNS-A. These status indications are: GPS position valid, Differential GPS position valid, Track and Ground speed valid, and altitude valid. The next thirteen bytes indicate the GPS derived latitude and longitude, altitude, track and ground speed.

The ADLP can be configured so that position reports will require an acknowledgment from a fixed repeater site once per minute. This acknowledgment is used to light a "NO DL" annunciator in the aircraft to indicate that they are beyond datalink coverage.

Position Report Message

<header><chksum><inp><adc><tod><stat><lat><lon><alt><trk_gs><chksum>

	# bytes	state of external strapping	1 = normal state, ungrounded
<inp>	1	bit 0	1 = pilot OK
			0 = pilot alarm
		bit 1	1 = squat switch (in air)

		0 = squat switch (on ground)
bit 2		1 = 10G shock inactive
		0 = 10G shock active
bit 3		1 = no repeat
		0 = repeat - allows ADLP to become "Top Cover" and relay messages beyond line-of-site of fixed station
bit 4		1 = 4 watt RF
		0 = 2 watt RF
bit 5		1 = mobile station
		0 = fixed station
bit 6		pilot interval selection
bit 7		pilot interval selection
		00 = no transmit
		01 = 15 seconds
		10 = 30 seconds
		11 = ABDS - Adaptive Broadcast interval - default mode
<ADC>	12	8 channels (10 bits of resolution - analog to digital conversion)
		Sensor allocation
		1-outside air temperature
		2-humidity
		3-indicated airspeed
		4-pressure altitude (icao converter)
		5- open
		6-heading
		7 turbulence
		8 icing
		Radar altimeter input 1
		Radar altimeter input if needed
<tod>	2	GPS time of day (seconds from midnight)
<stat>	1	status byte
	bit 0	upper bit of GPS time
	bit 1	1= position valid
	bit 2	1 = DGPS valid
	bit 3	1 = trk/gs valid
	bit 4	1 = altitude valid
	bit 5	1 = using external Electronic Data Interchange format (EDI) for GPS
		0 = using ADLP internal GPS for position
	bit 6	1 = local time
		0 = UTC time
	bit 7	not used
<lat>	4	latitude
		+ North, - South
		+/- (deg*60+min)*1000+tmin*
<lon>	4	longitude
		+ East, - West
		+/- (deg*60+min)*1000+tmin*
<alt>	2	altitude (meters)
<trk_gs>	3	track/ground speed
	0-4	not used
	5-14	ground speed (knots)
	15-23	track (true degrees)
<chksum>		

* tmin is equal to thousandth of a minute, or 6.07 feet. This is the smallest unit of position resolution that CNS-A resolves.









Text Message

<header><chksum><dest><data><chksum>

These messages are variable length up to 80 characters, and are interpreted by the end users of the system. Text messages typically support SIGMETS, AIRMETS, and other periodic broadcast of textual information.

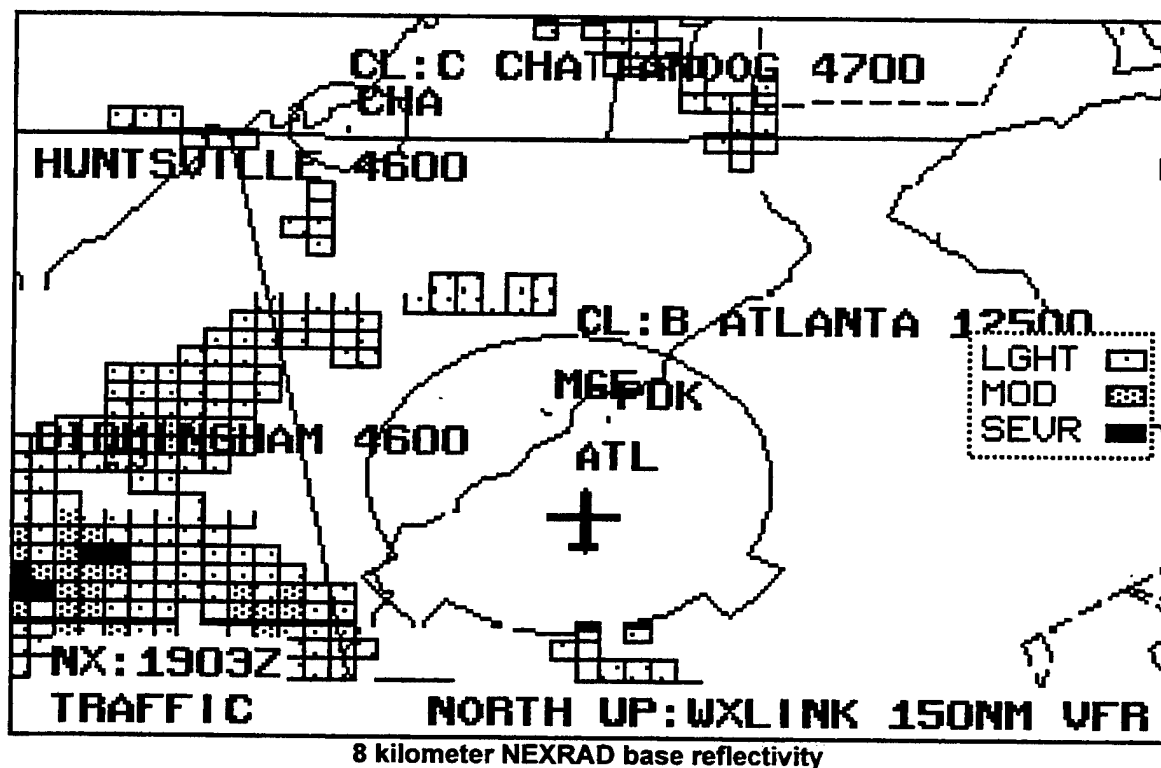
<dest>	3	24 bit destination ID	
<data>	1-80	bytes text	
	6	byte date	format MMDDYY
	6	byte time	format HHMMSS in military time
<chksum>	1	data checksum	

COCKPIT Display of Weather Data

<u>Monochrome</u>	<u>Meaning</u>	<u>Color</u>
	>=3000 > 5 nm VFR	 clear
	<3000, >=1000 < 5 nm, > 3nm MVFR	 green
	<1000, >=500 <3nm, > 1nm IFR	 yellow
	<500 ceiling < 1nm LFR	 red

Ceiling and Visibility information are displayed onto the Multi-Function Display when in mapping mode. The main elements of the Sequence Report (SA) form a Station Reporting Square, which is placed on the left side of the airport identifier. If no information is available, or if the information is older than the selected time aging, no reporting station square will be shown. Each reporting station square is divided into an upper **ceiling** category and a lower **visibility** category. The pilot can tell at a glance airports that are at or below minimums for VFR operations.

The full surface observation report is available by pressing a single button on the MFD.



METAR ICAO ZULU WIND VISIBILITY

METAR KATL 011856Z 08010KT 7SM OVC004
18/16 A3026 RMK A02 SLP245
T01830161

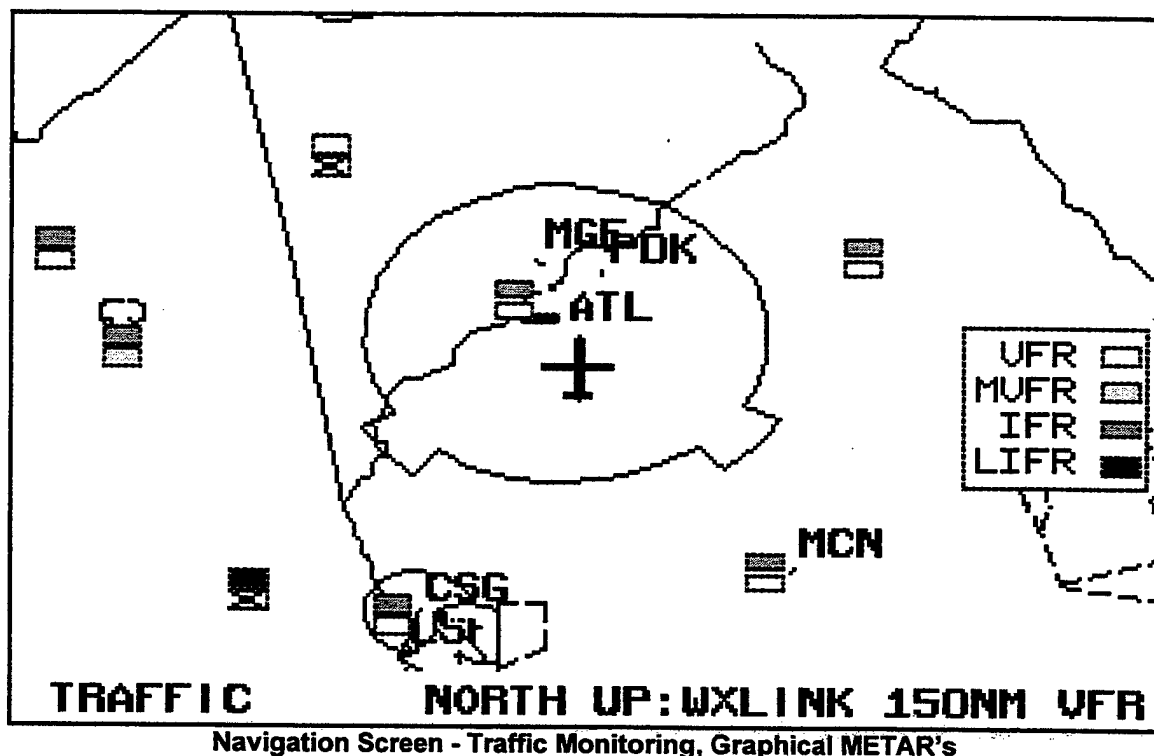
METAR KFTY 011847Z 09007KT 5SM BR OVC0
07 A3027

METAR KRMG 011848Z AUTO 11005KT 19/14
RMK PK WND 10///232 RNO

EXIT

PRESS ANY BUTTON

Text Display of DataLinked METAR's



BROADCAST WEATHER PROJECT

Broadcast Weather Project is a network of Ground Stations linked together to form an interoperable communication system that may be accessed by the Federal Aviation Administration, NWS, the aviation user community, and any other agency that has need of instantaneous weather products. The goal of Broadcast Weather Project is to distribute in real-time a set of high resolution, national weather products via a national wireless communication network to the aviation community and all of the National Weather Service - National Transportation Infrastructure users. These hi-resolution data sets will produce graphics presentations suitable for display on a flight-qualified graphics display in the cockpit.

The Broadcast Weather Project will use the thousands of general aviation aircraft that fly daily in the 3000 feet to 18,000 feet upper air region as airborne, real-time raw sensor collectors that will down-link the collected data via the ADLP. This altitude range is precisely where the National Weather Service has little to no data today, and has no plans for upper air measurements in the near future.

- This downlink data will be *smart*: it will know its location by way of the onboard, low cost, commercial-off-the-shelf global positioning system (GPS). The individual aircraft datalinks will always be geographically-tagged to cue the communications routers and modeling algorithms. Up to 50,000 active general aviation aircraft (ATC est.) will collect real-time aviation impact variable sensor data using low cost sensors fitted to the airframe. Combined with state-of-the-art Global Positioning System (GPS) parameters from the on board navigator, this weather data will have high value spatial and temporal qualities. **'Subjective' Data is eliminated:** Objective EPIREP onboard aircraft sensors yield absolute raw data and can be modeled on the surface to normalize the performance characteristics of the airframe.
- The data will be *quick* and *agile*; within 10 minutes, it will feed directly to a NWS weather field office (WFO) via commercial-off-the-shelf automated downlink. The data will then travel the established

NWS communications network to the forecasting centers. The centers will receive data from all over the USA to form the big picture. The forecasting centers will model with more real-time data than they have ever had, which will yield vastly improved weather products for all users. Simultaneously with the NWS data routing, a commercial workstation within the WFO will route the tagged data to NCAR in Boulder Colorado who will perform high level aviation gridded modeling in minimum time and redistribute the data back to the WFO for immediate uplink to the aircraft within 150 nautical miles of the WxStation. The resolved dataset will allow the pilot to select the gridded weather display presentation that best suits his flying conditions. Total time from raw data downlink to presentation can be less than 30 minutes.

- A local subset of the collected data will be broadcast every ten minutes as Electronic Pilot Reports via the same workstation and two-way datalink used to receive the downlink weather information. The data will also be simultaneously shipped from the WFOs, via an automated workstation, directly to a telecommunications router for local geographic-tagging and to Federal Aviation Administration designated facilities (ARTCC, FSS, TRACON).

Broadcast Weather Future Capabilities

There are four broad technical challenges that will need solutions in order to meet the Weather Network project goal. They are:

1. Automatically sense, detect, and forecast aviation weather hazards. This will require a focused scientific research program that will develop, test, and improve aviation weather detection and forecast algorithms. Airborne temperature, icing, turbulence, winter and summer storm movement and growth/decay, and ceiling and visibility are areas that require further study.
2. Create intelligent and integrated weather graphics displays for the airplane cockpit. By employing rapid prototyping technology to an incremental process that includes user feedback, an optimum user interface can be developed. The development of a low-cost, high resolution, flight qualified display meeting the needs of general, corporate and regional aviation is required. This as a crucial element in ensuring the capability to display weather products in the cockpit is flexible and affordable.
3. Create a national grid that incorporates aviation impact variables from all sensed and detected atmospheric data. Of critical importance is quick turnaround of real-time sensed data, and the return delivery of four-dimensional aviation weather graphics. Use of a grid format permits route and altitude specific processing to be efficiently accomplished by aircraft processing based on Global Positioning System position.
4. Transmit such grids and data to the aircraft cockpit in a form that will permit the creation of timely weather graphic products in response to pilot requests. The critical component of a complex, real time, airborne weather display system is an appropriate weather product server. A weather product server that integrates with a national network of aviation weather graphics and diverse airborne users has never been done before. Definition of broadcast text and graphic protocol Minimum Operational Performance Standards (MOPS), in conjunction with RTCA SC-169, must be expedited to allow avionics manufacturers time to develop the avionics necessary to take advantage of the Broadcast Weather.

Real-time collection and improved weather distribution will significantly improve the NWS specialized weather products to the national transportation sector: Trucking, marine, agriculture, forestry, drug enforcement, law enforcement and national security agents. It also provides excellent interface to the Intelligent Vehicle Highway System (IVHS) and Intelligent Transportation Systems (ITS)

The Weather Broadcast Project has three types of risk involved;

1. element risk, such as faulty or overly expensive aircraft weather parameter sensors. One of the design goals must be to minimize acquisition and recurring costs, while providing sensors that can survive in the extreme environment in which aircraft operate. Avionics manufacturers have adopted sensors from the automotive industry, and subjected them to exhaustive environmental testing to assure that they conform to DO-160C environmental standards. It is through the leveraging of the automotive industry volume that enables sensors cost to be kept at a minimum price.
2. programmatic system risk, such as NWS and FAA not employing the concept into the National Airspace system (NAS), or finding more advanced technology, or missing the acquisition opportunity because of unforeseen real world fiscal constraints.
3. technical risk - A critical component of a complex, real-time, airborne weather display system is an appropriate weather product server. The weather products envisioned for early implementation are composed of small-scale, rapidly changing weather parameters. Developing a model-based product server that identifies parameters, characterizes products, and disseminates weather information with the temporal and spatial specificity that is required for pilots to make tactical and strategic decisions has never been attempted. It is envisioned that this product server will compute weather hazards on a three-dimensional grid covering the continental U.S. with 40 vertical levels and 40 km (24 NM) horizontal resolution with forecasts out to six hours. This grid will generate nearly 960,000 data points for each hazard type (icing, turbulence, etc.) and hourly forecast period. Designing this product server is not without risk. It must transform the rapidly expanding volume of real-time and forecast meteorological data efficiently and effectively into very simple, low-bandwidth products tailored to the tactical and strategic needs of a pilot in flight along a specific four-dimensional trajectory.

In order to develop more accurate and timely weather depiction and forecasts of aviation weather hazards, one must incorporate the latest technological and scientific advances from a focused research and development program. This program would include development and testing that will evaluate hazardous aviation weather algorithms and products, initially focusing on the general aviation domain from 3000 feet through 18,000 feet. The program must evaluate:

- Airborne icing forecast algorithms;
- Turbulence detection and forecast algorithms;
- Winter snowband motion and summer thunderstorm motion algorithms, and
- Ceiling and visibility forecast products.

There are a variety of deficiencies and technical problems associated with these algorithms and products which require additional research.

Current airborne icing algorithms rely on numerical model outputs of temperature and humidity which do not reliably predict the occurrence of supercooled liquid water. The best current airborne icing algorithms have a probability of detection of 80% as confirmed by pilot reports, with a corresponding false alarm rate of 67%. [M.M. Cairns and B.G. Brown, "Product Documentation and Meteorological Verification for the FAA's 1995 AGFS/AWPG Demonstration and Validation," NOAA Forecast Systems Laboratory and NCAR Research Applications Program, 94 pp.] Driven by the high risk airborne icing events present to general aviation operations, an improvement of forecast icing is needed. Better results may be obtained by developing and testing a microphysical parameterization that will predict supercooled liquid water directly, instead of the current indirect derivation using temperature and relative humidity fields.

To supplement the icing guidance provided by the numerical forecasts, the location of icing conditions reported by pilots (PIREPs) will also be incorporated into the Broadcast Weather data assimilation and airborne display. Automated, electronic PIREPs that are near real-time should be extremely valuable in pin-pointing icing hazards for general aviation. Focused research by weather researcher must investigate the best methods for assimilating such data into a near real-time reporting scheme.

For turbulence, statistical verification of forecast results show a probability of detection of 33% as confirmed by positive pilot reports of turbulence, and a false alarm rate of 89%. [MM. Cairns and B.G. Brown] This poor performance is due both to a lack of physical understanding of the mechanisms causing turbulence and to the coarse vertical and horizontal resolution of current National Meteorological Center (NMC) operational models. Scientific research needs to be focused on improving our physical understanding through the use of aircraft-derived data gathered from field experiments addressing terrain-induced turbulence. Focus should initially be on low altitude hazards, those most confronting general aviation. This focus will, in the near term, be merged with high altitude hazards as the understanding of the interaction increases. The electronic PIREP program will assist with near real-time, high resolution information on wind and temperature fields. Modified algorithms will be developed, tested, and successful algorithms will be transferred to NMC for nesting in higher resolution turbulence forecasting and detection models.

Little or no information is available to the general aviation pilot inflight regarding convective weather hazards. Development of convective hazard products will use data from the newly deployed network of WSR-88D Doppler radar. Of interest to the pilot are the hazards associated with thunderstorms (such as hail, turbulence, heavy rain, lightning, icing), as well as the thunderstorm itself. Research will target these hazards for depiction to the pilot along with three-dimensional storm movement, growth and decay. These depiction's will permit route and altitude specific decision aiding for planning, and will not replace airborne radar, but will supplement them. The capability to track and predict the location of storms based on extrapolation of radar data already exists, but additional work is necessary to accurately predict motion of large scale summer and winter storm systems. This research will incorporate the use of radar echo strength, area coverage, and motion to enhance these algorithms. Also, research will address the problems associated with predicting the initiation and dissipation of thunderstorms.

Similarly, current models cannot meet the forecast requirements for ceiling and visibility, especially for visual flight rules which regulate the enroute portion of most general aviation flights. A variety of physical processes like fog, snow, and rain occur in the lowest 5000 feet of the atmosphere and make ceiling and visibility changes very difficult to anticipate and forecast. Research should commence to address the effects of snow and rain on visibility and ceiling through the development of an improved microphysical model that will directly compute snowfall and rainfall. Researchers should take advantage of ongoing work in boundary layer and four-dimensional data assimilation performed at NCAR. The effects of fog on ceiling and visibility are being addressed at MIT Lincoln Laboratory and the State University of New York, and will be incorporated as appropriate.

In all cases, timely collection of data on hazards as they occur will improve weather forecasting, and provide the inflight pilot a real-time picture of the actual weather situation.

Create Intelligent and Integrated Weather Graphic Display Requirements

Weather graphics will overlay electronic navigation chart selections, functionally relating weather to navigation and flight planning. The operational validation of user needs in this context presents a research challenge, since no attempt has been made to provide position-specific (route and altitude) weather products in the cockpit. Issues to be addressed include:

- Display quality and information transfer;
- Data fusion and information priority;
- User interaction with the display;
- Weather product selection and design, to include the use of the four- dimensional capability made possible by a gridded data base;
- Data base design to meet user needs and within the capability of the communications architecture.

Display design and operational validation of the user interface are iterative processes. In order to properly address these and other issues, we propose to establish an advisory users' group, which will be composed of representatives from the Federal Aviation Administration, NASA AGATE, commercial, general aviation, and corporate pilot groups. The advisory group will review prototypes of weather product concepts on displays containing navigation graphics referenced to GPS position. These inputs will be incorporated within a rapid prototyping environment, initially using the AGATE consortia members feedback to reduce risk prior to phased proofs of concept using actual aircraft. Rapid prototyping and feedback from the advisory users' group will continue throughout the system development.

A further technical challenge is to address these user needs in the integrated context of existing and new aircraft flying in the nation's airspace over the next 10-20 years, as well as the flight supporting functions of airline and general aviation weather users. A clear commercial relevance exists in establishing a "protocol" of aviation weather needs, not only for cockpit displays, but also for distribution among other private airline and general aviation functions like dispatch, flight operations, and flight planning.

Weather that is delivered in grid form to the aircraft cockpit will have the most benefit to the pilot. Processors on board the aircraft can then "slice and dice" the grid as necessary to present hazard volumes specific to the route and altitude of the aircraft, and at the proper time.

No infrastructure exists that will provide the capability needed. Ongoing projects are currently demonstrating the datalink of weather text and icons to the commercial and general aviation cockpit. These demonstrations are attempting to show user needs and benefits from such information. Clearly, the capability to show the pilot near real-time weather graphics—as opposed to text or icons—that are specific to his route and altitude will have enough value to warrant commercialization. The challenge is to make the capability automatic, inexpensive, reliable, and accurate. Developing a cheap means of delivery is crucial.

Portions of the Broadcast Weather already exists thanks to significant public and private investment. This network can expand to encompass WFO data collection sites, and will provide the resources needed to exploit the full potential of the network in aviation and this nation's transportation sector as a whole. A crucial element of the Broadcast Weather is the **allocation of one or more national VHF frequencies that will be dedicated to two-way weather transmission.**

The technical challenges that remain are to insure broad-based applications by designing the network in a growth potential. This is accomplished by insuring that a future broad-based weather capability can accommodate envisioned enhancements to transmission modes through an open architecture. Future transmission modes, such as VDL, SATCOM, digital cellular technology, or enhancements to VHF capability, will probably make available even greater bandwidth at less cost. The system will need to adapt as technology advances. Answers will emerge as system development and research continues, and awareness of the latest technological advances will allow for the greatest forward-fit applications.

Expansion to graphic portrayal of four dimensional weather information is the area of greatest benefit. This concept is unique in that it brings data together, processes it, and quickly disseminates information without a huge infrastructure investment. Furthermore, the Broadcast Weather infrastructure development represents a relatively low technological risk when compared to the research applied to weather product development and validation.

The current approach of others involved in aviation weather detection, prediction, and display include the FAA within the Federal Government, but without the focus on integrated pilot displays. Industry focus has not integrated a system with these components in a non-interpretive display with interactive interrogation of the system by the pilot. Academic organizations have pursued some of the associated technologies and scientific issues. Their results and progress will continue to be monitored and incorporated into this system, where applicable. The NASA/FAA/Industry/AGATE program is the ideal forum to integrate the technology onto a next generation aircraft, as well as receiving invaluable feedback through it's members.

The plan to achieve success of this effort includes a strongly coupled cross-disciplinary team of experts including air transport and general aviation pilots, cockpit human factors engineers, communications engineers, computer and software engineers, meteorological scientists, and algorithm developers. Within this team, the needs of pilots and other users will provide the driving influence to determine the direction of the scientific and technical efforts. The strongly coupled team will also provide an effective planning group for carrying out several discrete scientific and technical efforts concurrently, with an integration effort which brings them together into a single, end-to-end system.

This program provides an evolutionary foundation for a long-term process of performing advanced scientific and technical R&D and moving the most promising components through proof of concept into commercial development. Establishing this linkage between R&D and the commercial environment is critical if pilots are going to realize any benefits in the cockpit from the large federal investment in improved weather sensors and models.

Broad Impact on U.S. Technology and Knowledge Base

Although pilots have the regulated responsibility for the safe operation of aircraft, [See, for example, Code of Federal Regulations, Volume 14, Parts 91, 121, and 135.] much of what must be done to reduce the adverse effects of weather on safe and efficient airspace operations depends on controllers, dispatchers, and pilots individually formulating a shared picture of the aircraft's current and future surroundings. This shared picture, if it is to occur, would be one result of the huge scientific and technical capabilities that have developed from the Government's support of weather sensing, data processing, numerical modeling, display software, and weather algorithm development. This project will foster and create the necessary shared situational awareness in aviation weather at a time when the Government's plans for doing so have been called "unduly slow." [Weather for Those Who Fly, p.5] However, it will also foster and encourage the scientific disciplines and knowledge base of all the technologies which make this shared weather awareness possible.

Support for this project would build upon and broaden the Government's substantial investment in the nation's science and technology base. Applications developed here would build upon the National Science Foundation's support for numerical modeling applications at NCAR and several universities. NCAR's efforts to use very small scale model would augment the efforts of NOAA's Forecast Systems Laboratory to "nest" specific weather applications models within the National Meteorological Center synoptic scale forecast models. The capabilities of both the National Weather Service WSR-88D radar (NEXRAD) and the FAA's Terminal Doppler Weather Radar might be further enhanced by the development of both new product applications and new shared communication networks for weather products resulting from this project.

The detection and forecast of aviation weather hazards involves a variety of disciplines in the atmospheric sciences and engineering. A significant portion NCAR's annual budget of more than \$100 million goes to support research projects of the 61 universities owning its parent corporation, the University Corporation for Atmospheric Research. Support for this project will greatly encourage research applications of those university disciplines and the knowledge base they represent. Mesoscale observational and modeling sciences will be particularly encouraged to this project for support of applied science to develop advanced technology applications.

The potential impact of project funding on the knowledge base and technology of the U.S. is very great indeed. NWS and Federal Aviation Administration support for the detection and forecast of hazardous aviation weather, the creation of intelligent and functionally integrated aviation weather graphic displays, and for datalinking such graphics to the aircraft cockpit will improve the efficiency of Government agencies and private firms currently providing air traffic management and weather information services, as well as greatly improve the safety and efficiency of domestic air transport and commerce.

The Broadcast Weather system will greatly enhance safety in the cockpit, and decrease costly delays due to non-timely weather reporting. It offers more capability than weather radar or lightning strike detection. Pilots who do not have the onboard equipment will also receive great benefit through Flight Service Stations (FSS) and ATC's enhanced weather awareness.

Broadcast Weather is easily configured for interface to the ARINC Communications Addressing and Reporting System (ACARS). ACARS is an en-route Very High Frequency (VHF) digital communication system that will support inflight downlink of pilot reports. ACARS is currently installed in nearly 4,000 domestic commercial aircraft.

Broadcast Weather provides a symbiotic relationship between air carrier operations and general aviation aircraft because each provide different elements to the weather picture. Airlines operate in the lower atmosphere only around population centers (hub and spoke system) while general aviation fills in the gap left vacant by hub and spoke. Scheduled air carriers can safely dispatch into weather that General Aviation aircraft help to define by providing current conditions aloft.

Commuter / regional air carriers who do not have the extensive weather dispatch capabilities will greatly benefit from up-to-the-minute weather information in the cockpit. This fastest growing segment of aviation would derive the immediate benefit of increased weather awareness, as well as address the marketing problems created by the recent spate of weather related air crashes.

National Benefits of Weatherlink

The National Aviation Weather Program Plan (NAWPP) has identified 39 current unmet needs in order to realize a fully capable aviation weather system. Broadcast Weather provides possible solutions for 33 of these unmet needs. In addition, other government agencies could now have access to a vast body of real-time weather products as they are transmitted from the airborne platforms. These other agencies include:

Federal Aviation Administration:

The FAA has historically been a provider of aviation weather services rather than a producer. The FAA's principle role has been in the dissemination of products and services to the aviation community. With the implementation of Broadcast Weather and the EPIREP system, the FAA will increasingly become a generator of weather products. This is particularly relevant in the terminal area where time-critical response to short-lived hazards is imperative. Improving direct access to inflight weather will have a significant positive impact on safety and pilot efficiency, reducing the amount of weather information that ATC had to relay to pilots, thus freeing their time for important tasks of separating and managing air traffic.

National Aeronautics and Space Administration:

NASA is exclusively an end user of aviation weather information. NASA's aviation activities include Space Shuttle ferry operations, astronaut training flights, testing of prototype aircraft, airborne collection of space, atmospheric, and earth surface data to support scientific research, and routine flights between NASA facilities.

Department of Agriculture:

Aviation activities include wild land fire suppression, insect and disease surveys, animal damage control, law enforcement actions, aerial applications, and sterile insect release. Real time weather condition reporting will increase their ability to perform these functions.

Coast Guard:

The Coast Guard's aviation activities include maritime search and rescue, provisioning of maritime navigation aids, coastal patrol, and drug trafficking interdiction.

Department of Defense (Army, Air Force, Navy, Marines):

The DOD flies thousands of sorties in training, troop transportation, materiel disbursement, and weapons platforms. These missions are flown around the clock in all weather conditions. Enhancing the weather picture enhances the chances for success of these missions, and indeed, provide for a better preparedness in our countries defense.

NOAA:

The National Oceanic and Atmospheric Administration (NOAA) future aviation services include the Forecast Systems Laboratory's Aviation Gridded Forecast System (AGFS). The AGFS will provide high resolution, high frequency analysis of weather conditions, including cloud cover, winds, and weather reflectivity. This system depends upon a large number of data samples, which will be provided by the increased number of EPIREPs from the Broadcast Weather system. The AGFS will support quality improvements for terminal forecast, en-route forecasts, and nowcasts.

National Meteorological Centers:

The addition of thousands of EPIREPs will greatly enhance the National Meteorological Centers (NMC) ability to produce numerical grid winds aloft and temperature aloft forecasts.

NATIONAL ECONOMIC YIELD of Weatherlink -- the public benefit

There are a number of significant *benefits to the national economy* and technology base resulting from this concept.

- Further long-term research in the atmospheric sciences applied to weather forecasting and aviation, thereby effectively leveraging a \$4 billion U.S. Government investment in new atmosphere and weather sensing capabilities.
- Create a telecommunications system linked to a needed service that is commercializeable and expandable to other transportation modes.
- Provide a family of products that will have broad benefits to society in terms of more efficient use of air transportation resources, enhance air safety, and provide a revenue stream to expand this nation's technology base in the atmospheric sciences and telecommunications.

Virtually every specialized user of the NWS forecast service family of products will benefit from Broadcast Weather. The National Transportation Infrastructure will be safer and much more efficient when commercial buses, trucks and inland marine vehicles, search and rescue, agriculture, and public schools and events can avoid dangerous weather conditions and costly operational delays.

Economic Payback of Weatherlink

Estimates of potentially recoverable aviation delay and safety benefits attributable to enhanced weather detection and forecasting run in terms of billions of dollars. For example, the FAA estimates that reducing weather related delays in aircraft operations by 15% over the next ten years could save \$5.3 billion. [John A. Burt, "System Development Program Review," Federal Aviation Administration, Washington DC, 1993.] The Air Transport Association has estimated that weather related delays cost commercial aviation about \$1.7 billion per year. Even very small improvements in aircraft enroute operating costs (.04%) such as attributed to onboard weather displays in NASA simulations, could result in annual operating savings of greater than \$50,000 per commercial aircraft. [Charles Scanlon, "Cockpit Weather Information Needs," presentation to Aviation Users Conference, Washington DC, February 3, 1994.] Overall, about 20% of FAA's aircraft operations delays in 1992 were attributable to weather and about 65% of operations delays greater than 15 minutes were weather related. [Burt.] There also are very large costs associated with uncertainty about weather forecasts. Between 1981 and 1986, about 40% of the FAA's decisions to hold aircraft on the ground due to weather-impacted capacity were unnecessary and caused delays. [Steve

Boswell, "Estimating Nationwide Savings from Improved Aviation Weather Services," Air Traffic Automation, Lincoln Laboratory, MIT, July, 1992.]

Minimizing even a single aircraft delay at one destination is highly consequential. It could reduce subsequent delays throughout the aircraft's remaining flight schedule by as much as five times the initial delay saving. More fuel efficient descent profiles and routes could be planned if pilots and controllers could reliably anticipate and track weather disruptions.

Federal Aviation Administration will be aiding other transportation related technologies that are critical to the nation's global competitiveness by supporting this project, such as the Global Positioning System.

Federal Aviation Administration support for this project will also encourage broader, weather related applications of these technologies in other transportation domains. Examples include trucking, overnight delivery services, maritime, rail, bus, and IVHS applications.

The future impact of Broadcast Weather on the nation's transportation system will be far reaching because it can provide a better weather representation relative to navigation fixes, as well as provide a fault tolerant navigation system that is independent from outside signals.

Broadcast Weather can promote and encourage cockpit modernization by providing an environment where pilot training and re-training can be reduced, thereby increasing the utility of the general aviation aircraft as a transportation tool. This is the cockpit 2000 concept that has been recommended as the goal for better human factors cockpit environments by the industry, NASA & the FAA in recent advisory recommendations, e.g. [Holmes, Fiduccia & Weiss 1993].

To summarize, the Broadcast Weather data distribution system should be offered initially to the general aviation market, where the inherent value of such a product is anticipated to create collateral demand for multi-function displays and data link. Weather product enhancement will occur as more aircraft participate in the collection of atmospheric data. This will, in turn, create more demand. Marketing efforts will parallel in other modes within this nation's transportation sector as more tailored weather information is developed.

Functional Hazard Analysis

The following charts represent the functional hazard assessments necessary to receive Supplemental Type Certification on the CNA-A equipment. These FHA's are provided for Moving Map Situational Awareness Information, Position Reports, Cockpit Display of Traffic Information (CDTI), Weather Information (Text, Graphical Ceiling and Visibility, Graphical NEXRAD), Two-Way Text Messaging, Electronic PIREPS

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/ Malfunction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ¹	Effects Class
Moving Map Situational Awareness Information Aircraft position relative to certain geographic and airspace features, used for situational awareness in under VFR.	Aircraft position relative to navigation aids, airports, major geographic features, charted obstructions, and special use airspace.	1. Pilot Misuse.	F5	1.a. Pilot use as sole means of navigation.	1.a. Flight manual procedures and limitations and placarding specifying VFR use only and providing that all navigation must continue to be done by conventional means.	1. V
		2. Loss of Function.		1.b. Pilot use for IFR navigation.		2. IV
		3. Malfunction.		2. No navigation display. 3. Inaccurate navigational information.	1.b. Procedures, limitations, and placarding. 2. Pilot easily can determine loss of function, and reverts to other means of navigation. 3. Pilot in cross checking charts or navigational aids determines any significant navigational error not within the tolerance of conventional navigational aids.	3. IV

NOTES:

1. Aircraft Flight Manual, Normal Operating Procedures:
GPS or LORAN accuracy may vary. Moving map features, such as major geographic features, navigational aids, airports, and obstructions are intended only for situational awareness. Navigation must be conducted by reference to charts or navigational aids.
2. Aircraft Flight Manual, Limitations:
GPS moving map has been approved for operation under Visual Flight Rules (VFR) only. Navigation must not be based on GPS alone..

¹ Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfunctions.

3. Placard: GPS moving map VFR Use Only

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/ Malfunction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ²	Effects Class
Position Reports Automatic broadcast of aircraft position to the ground; used for dispatch office aircraft tracking, VFR flight following for situational awareness, and search and rescue enhancement purposes only.	Aircraft ID, time, latitude, longitude, altitude.	1. Pilot misuse. 2. Loss of function. 3. Malfunction.	F5	1. No pilot interaction. 2. Failure to make position reports. 3. Inaccurate position reports.	1. N/A. 2. Aircrew reverts to position reporting by voice communications for dispatch purposes. VFR flight following reverts to either radar coverage or non-radar procedures. Search and rescue methods revert to standard practices. 3. Dispatch tracking errors have no safety impact. VFR flight following is for situational awareness, not separation or navigation; significant errors can be cross checked by voice communication reports of position (similar to encoding altimeter errors).	1. V. 2. IV. 3. IV

² Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfunctions.

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/ Malfunction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ³	Effects Class
Cockpit Display of Traffic Information (CDTI). Used under VFR in VMC to assist visual acquisition for "see and avoid" actions, with evasive maneuvers taken only after traffic is seen. Continued use of radar and pilot/controller communications for separation or flight following.	- Graphical display of relative aircraft position, target bearing, range, altitude difference, and descent or climb indication; levels of hazard warning. - Typical 5 sec data update rate; 5 second typical position latency.	1. Pilot misuse. 2. Function loss 3. Malfunction	F5	1.a. Pilot is "entranced" by display, fails to look outside cockpit. 1.b. Pilot maneuvers solely by reference to the CDTI. 2. Loss of display. 3. Traffic is shown in a position other than its correct location, or traffic is not shown at all.	1.a. Pilot is trained to use display as part of normal instrument/traffic scan, with only momentary reference. 1.b. POH limitations prohibit this use; if flight following, controller sees maneuver. 2. Pilot reverts to other data sources (visual acquisition and ATC communications) for traffic acquisition. 3. POH Normal Operating Procedure (see below):	1.a. V 1.b. V 2. IV 3. IV

NOTES:

1. Aircraft Flight Manual, Normal Operating Procedures:

All traffic is not shown on display because it may not be equipped or its equipment may not be operating; traffic may not be in displayed position because of maneuvering of either aircraft combined with data latency and update rate; search for aircraft within a 30 degree cone of the displayed

³ Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfunctions.

position, if aircraft is not immediately observed where the display indicates, then the full normal outside scan should be performed to locate the traffic and ATC should be contacted if already in communication. Unit is placarded for VFR only limitation. A primary voice communication system compliant with the operating rules (e.g., VHF voice) is required.

The pilot should not initiate evasive maneuvers using information from the CDTI traffic display only without visually sighting the traffic. These displays are intended only for assistance in visually locating the traffic and lack flight path trends necessary for use in evasive maneuvering.

2. Aircraft Flight Manual, Limitations:

"The CDTI application has been approved for operation under Visual Flight Rules (VFR) only." In no case should the pilot take any evasive action without either visual acquisition or a controller suggestion or direction to deviate.

3. Placard: "CDTI VFR Use Only"

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/Malfuction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ⁴	Effects Class
<p>Text Weather (SA); Graphical Ceiling/Visibility; Graphical NEXRAD Precipitation.</p> <p>Used to assist if weather hazards for "see and avoid" actions taken based on visual observations.</p>	<p>- Text: SA, SP, notice of SIGMET and AIRMET; latest observation; 10 minute latency.</p> <p>- Graphical representation of ceiling and visibility (VFR, MVFR, IFR, LIFR); latest observation, 10 minute latency.</p> <p>- NEXRAD mosaic 15 to 30 minute latency; 8 km resolution.</p>	<p>1. Pilot misuse.</p> <p>2. Function loss.</p> <p>3. Malfuction.</p>	F5	<p>1. Pilot uses NEXRAD for weather penetration, despite data latency and resolution limitations.</p> <p>2. Pilot loses weather data display.</p> <p>3. Display shows clear area where there is severe weather; shows VFR airport ceilings and visibilities where they are IFR.</p>	<p>1. Pilot is trained in limitations of data, latency and resolution, and that the intended purpose is for strategic, not tactical, decisions.</p> <p>2. Not required to conduct normal operations. Loss readily apparent to flight crew. Flight crew resorts to primary voice communication system compliant with the operating rules (e.g., VHF voice). Pilot reverts to visual weather hazard acquisition and use of EFAS, controller communications describing location and severity of weather, and any on-board real time information..</p> <p>3. No operational use without an independent means of verification. ATC radar and pilot/controller communications provide independent means to verify requests into inclement weather. Pilot may only use NEXRAD data to assist in acquiring and assessing convective activity when VMC; EFAS and controllers should be used as cross check clear areas described by display; ATIS is used to confirm airport surface conditions.</p>	<p>1. V</p> <p>2. IV</p> <p>3. IV</p>

⁴ Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfuctions.

NOTES:

1. Aircraft Flight Manual, Normal Operating Procedures:

Graphical weather precipitation information on GWS is to be used only as a strategic planning tool, for use to make decisions on circumnavigating precipitation areas that are out of visual range or where the extent of the precipitation areas cannot be seen, or where poor visibility makes visual acquisition of hazardous weather difficult, with decisions to deviate made well in advance or contact with the precipitation. It may be used in two ways:

- a. To aid the pilot in visual acquisition of precipitation areas; and/or
- b. As a cue to call either Flight Watch or the ATC controller in contact with the aircraft to get further information about the precipitation area.

In either case, the pilot should not make any deviation solely based on the GWS display, but should make these decision based on whatever other real-time information the pilot has access to regarding precipitation areas.

The pilot may not initiate evasive maneuvers solely using information from the GWS precipitation display. The TIS display is effective only for assistance in visually acquiring other aircraft. Because of time delays inherent in the mosaic and data link system, GWS lacks the resolution and updating rate needed to allow accurate tactical evasive maneuvering around precipitation areas solely based on the display. Maneuvering while flying in IMC could be especially hazardous in that the pilot could create a hazard that did not otherwise exist. When IFR, all deviations must be made pursuant to a clearance amendment or permission to deviate for weather, and based on real-time sources of weather information.

The pilot may not initiate evasive maneuvers solely using information from the GWS precipitation display. The TIS display is effective only for assistance in visually acquiring other aircraft.

2. Aircraft Flight Manual, Limitations:

"The NEXRAD graphical precipitation map application has been approved for operation under Visual Flight Rules (VFR) only." In no case should the pilot take any evasive action without real time information on precipitation areas.

3. Placard: "Weather for VFR Use Only"

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/ Malfunction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ⁵	Effects Class
Two way text messaging. - "Canned" commonly used messages that may be selected with one button push, for use in the air or on the ground. AOC messages in commercial use; simulated ATC messages for ASTS testing only. - Free text messages, for use by observers or passengers, or by pilots on the ground only for flight plan filing.	10 separate canned messages, commonly used by pilots in normal operations. All commercial use will be for AOC purposes. Free text compositions: typically flight plan information for AOC purposes.	1. Pilot misuse. 2. Loss of Function. 3. Malfunction	F5 G2 for composed text	1. Pilot spends excessive time composing messages. 2. Loss of messaging capability. 3. a. Scrambled, unreadable messages. 3. b. Inaccurate messages.	1. Flight manual limitation against composing messages in flight. 2. Revert to VHF voice communications. 3. a. Obvious to pilot, request retransmission. 3. b. "ATC type" messages are for ASTS test purposes only, no actual ATC use. No action will be taken based solely on these messages. The messages can be changed for different users, and will be for AOC purposes only in commercial products.	1. IV 2. IV 3.a. IV 3.b. IV

NOTES:

1. Aircraft Flight Manual, Normal Operating Procedures:

Canned text messages may be selected by the pilot or other aircraft occupants in flight.

Free text messages may be composed by the pilot only pre-flight or post-flight for AOC flight plan filing and other communications. In flight, the free text composition feature may be used only by a non-flying pilot, observer or passenger.

⁵ Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfunctions.

2. Aircraft Flight Manual, Limitations: The pilot may not use the free text message composition function in flight.
3. Placard: Free text message composition not to be used by pilot in flight.

Function Operational Concept	Data Elements Description	Failure Description Misuse/Loss/Malfunction	Phase of Flight	Failure Conditions	Failure Effects Mitigation ⁶	Effects Class
Electronic PIREPS (EPIREPS) Automatic transmission of airborne weather data by the aircraft to the ground or other aircraft. For use as additional weather data by weather forecasters. For use by pilots for situational awareness.	Aircraft ID, latitude, longitude, altitude, temperature, dew point (or other moisture measure), perhaps wind speed and direction.	1. Pilot misuse. 2. Loss of function. 3. Malfunction.	F5	1. No pilot interaction on transmission. Pilots equipped to receive EPIREPS could misinterpret data transmission. 2. No transmission of data. 3. Transmission of inaccurate data.	1. For aircraft equipped to receive EPIREPS, pilot training to treat all EPIREPS messages as a UA (unreliable airman) observation. 2. Revert to current systems. 3. Pilot cross check with other data sources as is currently done.	1. V. 2. IV. 3. IV.

1. Aircraft Flight Manual, Normal Operating Procedures:

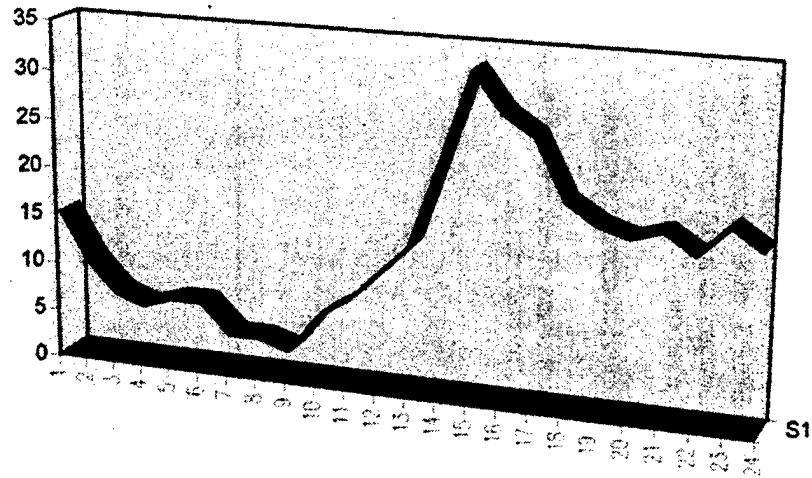
Pilots should treat EPIREPS data as other PIREPS UA data (unreliable airman), it is not independently verified and must be cross checked against other data sources.

2. Aircraft Flight Manual, Limitations: None.

3. Placard: None.

⁶ Failure Effects Mitigation includes: 1) training and procedures; 2) placarding; 3) instructions on data limitations presented on the display; 4) alternative sources of data to cross check for malfunctions.

07-29-96 Vehicle Density



07-20-96 - Vehicle Density Zulu Time

